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ENGINEER MANUAL

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ENGINEERING AND DESIGN

GUIDELINES FOR DEWATERING/DENSIFYING CONFINED DREDGED MATERIAL

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DEPARTMENT OF THE ARMY
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Engineering and Design
GUIDELINES FOR DEWATERING/DENSIFYING CONFINED DREDGED MATERIAL

1. Purpose. The purpose of this manual is to discuss the major concerns and provide information about design, construction, operation and management of containment areas for dredged material wherein the material is dewatered and densified. This dewatering is done in order to create fast land suitable for productive land use and development.

2. Applicability. This manual applies to all field operating agencies concerned with the Civil Works design, construction and management of dredged material disposal areas.

3. General. Dredged materials usually placed in confined disposal areas are in a semifluid state that requires removal of large amounts of water in order to densify the material. The dewatering operation is desirable in that (1) it creates more volume in existing disposal sites for additional dredged material; (2) the densified soil may be used for other engineered construction thereby creating more volume at the disposal site, and (3) stable fast land suitable for many purposes is created. This manual provides information and guidance concerning dewatering and densification of confined dredged material. It will help the design engineer and disposal site manager to understand and develop the best methods for underdrainage and surface drainage of the containment areas. The methodology and guidelines presented in the manual will assist the design engineer in determining what is technically feasible, operationally practical and cost-effective for dewatering of the containment areas.

4. Design Priorities. The Corps has been engaged in a Dredged Material Research Program (DMRP) and the results of the efforts are either published as Synthesis Reports or DMRP Reports. Since these Synthesis Reports have been prepared in a "how to do it" form, OCE has also decided to include them in the Engineer Manual 1110 series. All such Reports will have numbers above EM 1110-2-5000 (i.e. 5001, 5002, ...5025). However, since some of these reports are too generalized and lacking sufficient technical information to be used for the design of a project, the design engineer must consider other engineer manuals as having priority where overlap of a particular subject occurs. At such a time when the information discussed in this EM 1110-2-5000 series of manuals overlaps or is contradicted by

another engineer manual or Engineer Technical Letter (ETL) of the 1110 series, the latter will have precedence. This is because the Synthesis Reports have not been prepared in the detail required nor given the technical review and approval of the Engineering Division in OCE.

FOR THE CHIEF OF ENGINEERS:

THORWALD R. PETERSON
Colonel, Corps of Engineers
Executive Director, Engineer Staff

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GUIDELINES FOR DEWATERING/DENSIFYING CONFINED DREDGED MATERIAL

PART I: INTRODUCTION

1. Dredged material is usually placed in confined disposal areas hydraulically in a slurry state. Although a significant amount of water is removed from it through the overflow weirs of the disposal area, the confined fine-grained dredged material usually sediments/consolidates to only a semifluid consistency that still contains large amounts of water. The volume occupied by the liquid portion of the dredged material greatly reduces available future disposal volume. Also the extremely high water content makes the dredged material unsuitable or undesirable for any commercial or productive use.

2. Three major reasons exist for dewatering fine-grained dredged material placed in confined disposal areas:

a. Promotion of shrinkage and consolidation, leading to creation of more volume in the existing disposal site for additional dredged material.

b. Reclamation of the dredged material into more stable soil form for removal and use in dike raising, other engineered construction, or other productive uses, again creating more available volume in the existing disposal site.

c. Creation of stable fast land, from the disposal site itself, at a known final elevation and with predictable geotechnical properties.

3. In order to properly evaluate the benefit-cost ratio of dewatering fine-grained dredged material, it will be necessary to adopt long-term planning concepts. In the great majority of instances, application of such concepts will show that the expenditure of additional capital in proper disposal site design and construction, as well as in a continuous of semicontinuous dewatering program will result in a lower unit volume disposal cost over the entire operating life of the site. Lower costs result from the additional site volume gained by dredged material dewatering and the potential cost savings involved in use of dewatered material for dike raising on other productive uses.

Finally, the end result of a continuous dewatering program over the disposal site life will be creation of fast land, usually satisfactory for productive land use and development. This factor should make it easier to obtain agreements to provide confined disposal area acreage.

PART II: DEWATERING BY PROGRESSIVE TRENCHING

Introduction

4. Allowing evaporative forces to dry fine-grained dredged material into a crust while gradually lowering the internal water table was the least expensive and most widely applicable dewatering method identified during the Dredged Material Research Program (DMRP).[1,1A,2] Good surface drainage, rapidly removing precipitation and preventing ponding of surface water, accelerates evaporative drying. Shrinkage forces developed during drying return the material to more stable form, and lowering the internal water table results in further consolidation. The most efficient method of promoting good surface drainage is by constructing drainage trenches in the disposal area.

Conceptual Basis for Dewatering by Progressive Trenching

5. The following mechanisms were found to control evaporative dewatering of fine-grained dredged material placed in confined disposal areas:

a. Establishment of good surface drainage allows evaporative forces to dry the dredged material from the surface downward, even at disposal area locations where precipitation exceeds evaporation (negative net evaporation).

b. The most practical mechanism for precipitation removal is by runoff through crust desiccation cracks to surface drainage trenches and off the site through outlet weirs.

c. To maintain effective drainage, the flowline elevation of any surface drainage trench must always be lower than the base of crust desiccation cracks, else ponding will occur in the cracks. As drying occurs, the cracks will become progressively deeper.

d. Below the desiccation crust, the fine-grained subcrust material may be expected to exist at water contents at or above the liquid limit (LL). Thus, it will be difficult to physically construct trenches much deeper than the bottom of the adjacent desiccation crust.

e. To promote continuing surface drainage as drying occurs, it is necessary to progressively deepen site drainage trenches as the water table falls and the surface crust becomes thicker, thus the name "progressive trenching" for the concept.

f. During conduct of a progressive trenching program, the elevation difference between the internal water table and the flowline of any drainage trench will be relatively small. When the relatively low permeability of fine-grained dredged material is combined with the small hydraulic gradient likely under these circumstances, it appears doubtful that appreciable water can be drained from the dredged material by gravity seepage. Thus, criteria for trench location and spacing should be based on site topography so that precipitation is rapidly removed and ponding is prevented, rather than to achieve marked drawdown from seepage.

Effects of Dewatering

6. The net observable effect of implementing any program of dewatering by improved surface drainage will be fivefold:

a. Disappearance of ponded surface water.

b. The majority of precipitation will run off the site within a few hours.

c. The dredged material will be gradually dried to more stable soil form.

d. Vertical settlement of the surface of the disposal area.

e. Vegetative cover may become established on the site.

7. The time necessary for establishment of viable vegetative cover in confined disposal areas after surface drainage improvement is initiated is not well-known. This time is likely to be highly site-specific, depending on:

a. The extent and nature of the surrounding native species.

b. Salinity of the dredged material pore water.

c. Precipitation frequency at the disposal site.

Removal of surface water should promote conditions conducive to establishing vegetation in the disposal area, though there will probably be some time lag when the native community surrounding dredged material with initially saline pore water consists of freshwater species. In such instances, continuing precipitation runoff will normally provide necessary salt leaching of the upper crust to allow freshwater vegetation establishment. The height of vegetation may also control drying rate. Tall vegetation, shading the surface and restricting surface wind airflow, may actually inhibit evaporation. Low-profile grasses may be the best vegetation for disposal areas.

8. In one well-documented instance,[1] a dense volunteer freshwater vegetative cover was obtained within 6 months after initiation of improved surface drainage on fine-grained dredged material having an initial pore water salinity equivalent to seawater. Similar dredged material in an adjacent disposal area not subjected to improved surface drainage remained bare. However, the established vegetation did not appreciably affect the dewatering rate.

Consideration of Climatic Conditions

9. Evaporative drying of fine-grained dredged material into more stable soil form and vertical subsidence of the disposal area surface from a combination of desiccation shrinkage and increased effective stress consolidation are also highly site-specific effects. However, fairly reliable estimates of expected behavior may be obtained based on site climatological conditions and engineering properties of the dredged material.

10. Meteorological parameters needed to conduct a preliminary analysis include the average annual precipitation and the average annual Standard Class A Pan Evaporation expected at the disposal site. The average annual precipitation is normally available from records maintained by the National Weather Service; the measurement location closest to the disposal site is normally satisfactory for use. The average annual Standard Class A Pan Evaporation is a measure of the amount of fresh water (normally expressed in vertical inches or centimetres of water) evaporated from a metal pan of specified size and water depth

when exposed to existing climatological conditions. Class A Pan Evaporation normally approximates the maximum amount of water which may be evaporated under existing climatic conditions. Should Class A Pan Evaporation data not be readily available for the disposal site from the National Weather Service or the U. S. Department of Agriculture, data provided in Appendix A may be used for estimating purposes.

11. If the average annual precipitation is less than the Class A Pan Evaporation at the disposal site, it is likely that some dredged material desiccation and vertical surface subsidence will occur, with or without a surface drainage improvement program. To obtain an indication of the annual unaided dredged material dewatering that will occur from evaporative forces, the difference between average annual precipitation and Class A Pan Evaporation should be used as the evaporative parameter in equations and relationships described subsequently in paragraphs 26-57.

12. If the average annual precipitation is greater than the Class A Pan Evaporation, it is doubtful that significant dredged material dewatering will occur without improved surface drainage. If dewatering is to be accomplished by improved surface drainage, then the average annual Class A Pan Evaporation is the evaporative parameter to be used in subsequently given relationships.

13. Evaporative drying proceeds in three stages;[3] the first two are important in fine-grained dredged material dewatering. First-stage evaporative drying proceeds at a rate similar to that of a free water surface, while second-stage drying is governed by capillary resupply potential of the soil. Under conditions normally found in confined disposal areas, long-term dredged material evaporative drying is essentially a second-stage process. Wetting of the dredged material surface during precipitation may increase the evaporation rate to the higher first-stage level for short periods, but this higher drying rate serves only to rapidly remove precipitation which does not run off through desiccation cracks into surface drainage trenches. Predictions developed herein assume an annual evaporative drying rate based on continuous second-stage drying. Obviously, evaporative dewatering will not occur

when the dredged material pore water is frozen; effects of such climatological periods will be reflected in Class A Pan Evaporation data. However, freeze-thaw behavior may provide additional densification of fine-grained dredged material.[4]

14. For fine-grained dredged material with saline pore water (i.e., the result of saltwater dredging), a surface trenching program will result in annual dredged material water loss about equal to 35 percent of the average annual Class A Pan Evaporation. If the dredged material pore water is fresh (i.e., the dredged material is a product of freshwater dredging), approximately 50 percent of the Class A Pan Evaporation value may be removed from the dredged material.

Consideration of Dredged Material Engineering Properties

Accuracy of prediction equations

15. The relationships and equations given herein and subsequently illustrated by example are greatly simplified and should be used only for determination of initial feasibility relative to whether or not dewatering should be attempted. Once such feasibility has been determined, a more detailed analysis, such as that described by Hayden,[5] should be undertaken. The analysis should consider the interaction between the desiccation and consolidation phases. Also dredged material crust formation, surface subsidence, and subcrust consolidation should be better related to time after initiation of dewatering operations. It is also necessary to predict more accurately the optimum starting time for such operations after the disposal process is terminated. The relationships and equations presented herein are for predicting the behavior of dredged material obtained from essentially fine-grained channel sediment. A small percentage of sand (less than about 25 percent) may exist in the channel sediment, and this sand is assumed to be dispersed uniformly throughout the sediment, such that the average channel sediment water content is controlled by the fine-grained fraction. When the sediment is dredged, the sand is assumed to fall out of suspension around the dredge pipe location and not be contained in the fine-grained

fraction subjected to dewatering. Therefore, to properly predict dewatering effects, the Atterberg limits (LL and plastic limit (PL)) of the channel sediment should be run on the sediment fraction passing the U. S. No. 200 sieve rather than the No. 40 sieve. Also, if the channel sediment contains more than about 25 percent sand sizes or the dredging operation is to be conducted along a reach containing appreciable pockets of sand, more refined predictive methods[5,6] should be used to consider the effects of the cohesionless material. Further, results predicted from the assumptions, equations, and relationships may be achieved only if an active dewatering program is initiated and maintained over the entire site.

Dredged material evaporative drying

16. The total volume gain in the disposal area from evaporative dewatering will be equal to the volume of water lost, i.e., either 35 percent or 50 percent of the evaporative input parameter. Under field conditions, it has been found that the volume in the desiccation cracks amounts to only 8 to 25 percent of the volume created by vertical subsidence. In lieu of better data, a value of 20 percent may be used for prediction purposes. The thickness of dredged material dried to more stable soil form annually by evaporation will depend upon the engineering properties, particularly those relating to plasticity, of the fine-grained dredged material. It has been found that, left to its own devices, fine-grained dredged material will, after an extended period, reach a water content* approximating its LL.[2,7,8] However, first-stage drying has been found to stop and second-stage drying to begin as the dredged material reaches a water content of about 1.8 × LL.[3] This point represents the end of the free water decant phase and is called the "decant point." The crust water content under second-stage drying has been found experimentally[1,3] to remain fairly constant at a value of approximately 1.2 × PL.

17. No practical advantage exists for initiating a surface

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* As used herein, water content is defined as the weight ratio of water to soil solids, expressed as a percentage.

trenching program until the water content of the dredged material has reached the decant point, since evaporation rates prior to this time are controlled by first-stage or free water surface behavior. The minimum elapsed time necessary between termination of disposal operations and initiation of a surface trenching program is highly site-specific and dependent upon existing dredging, disposal area, and climatological conditions. This time could range from 1 to 6 months. Procedures for predicting this minumum time are available elsewhere.[5] The decant point may be observed in the field when a thin drying skin forms on the freshly placed dredged material and widely spaced desiccation cracks occur in the skin; this condition is shown in Figure 1. The decant point is related to the evaporative drying conditions and is not directly related to dredged material sedimentation, self-weight consolidation, nor the transition between the two. The value of 1.8 × LL is a statistical

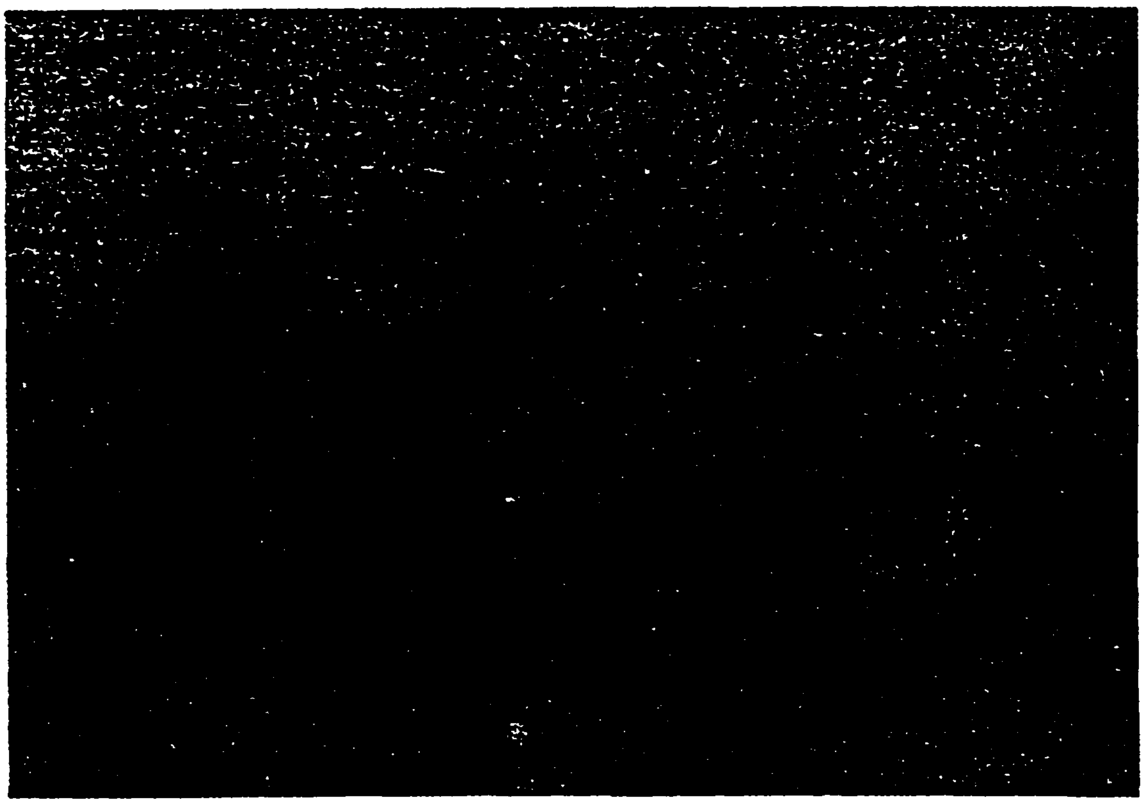


Figure 1. Surface of fine-grained dredged material at the earliest time when surface trenching should be attempted; initial cracks are spaced at 3- to 6-ft intervals and the surface water content approaches 1.8 × LL

average of available data and is reached during the self-weight consolidation phase. If actual water content measurements are taken when the dredged material reaches the consistency shown in Figure 1, these data may be used in subsequent equations to obtain better predictions.

18. If the dewatering program is initiated once the material has reached a water content near 1.8 × LL, it may be assumed, for estimation purposes, that the crust formed from evaporative drying will have a water content equal to 1.2 × PL, while the subcrust dredged material will, initially, remain at a water content equal to 1.8 × LL. Thus, the amount of fine-grained dredged material dried to more stable soil form will depend upon the amount of water removed from the material, as compared to the amount of water necessary to dry the material from its existing water content to 1.2 × PL. If the grain-size distribution, average Atterberg limits, existing natural water content, and specific gravity of solids G_s are known for the channel sediment or for the existing dredged material, the additional disposal volume and amount of crust creatable through evaporative drying may be estimated. Necessary equations are given in paragraphs 26-54.

19. If dewatering operations are postponed past the decant point water content, the dredged material water content will decrease very gradually toward the LL, and a thin desiccation crust several inches thick may form on the surface. When this existing dredged material is subjected to a dewatering program, the effects of dewatering will be related to the existing crust thickness and average subcrust water content, in addition to the engineering properties described previously. Necessary equations for defining this behavior are given in paragraphs 42-54.

Dredged material
subcrust consolidation

20. The internal perched water table in the disposal area is assumed to be lowered to the base of the crust produced by evaporative drying. Additional vertical subsidence will be caused by consolidation of the dredged material beneath the surface crust, under increased effective stress caused by water table lowering and removal of buoyant

force. An estimate of vertical consolidation settlement may be obtained by assuming the subcrust dredged material to be normally consolidated and using standard one-dimensional consolidation relationships to predict the settlement caused by removal of buoyant force. A necessary parameter in the analysis is the compression index C_c , best obtained by performing a consolidation test[9] on the material. Guidelines are available[1,5] for conducting consolidation tests on extremely soft channel sediment or dredged material. In the absence of consolidation test data, very approximate relationships have been determined between the LL and C_c of dredged material[10] such that $C_c \approx 0.007\ (LL - 5)$, if the material is dried before LL testing, and $C_c \approx 0.002\ (LL + 1.3)$, if the LL test is started with the material at natural water content.

21. For gross approximation purposes, the parameter C_c may be taken as unity (1), though this should be done only as a last resort. Once these data are available, the amount of vertical settlement resulting from consolidation may be estimated. The main sources of error in all simplified consolidation predictions contained in this report are the neglect of time and secondary consolidation effects. It is assumed that all primary consolidation produced by increased effective stress will take place very rapidly after the stress is applied. While the assumption is acceptable for the majority of instances, more precise prediction methods[5,6] are available.

<u>Period for expected drying benefits</u>

22. At most disposal sites where precipitation exceeds evaporation, second-stage drying will continue indefinitely as long as adequate surface drainage is provided. Thus, evaporative drying will continue for the entire period between disposal cycles if good surface drainage is maintained, with the dredged material being dried into crust at an approximately linear time relationship. For partial year periods, evaporative data for the specific months in question may be obtained from Appendix A. It should be noted that the effective limit of evaporative drying is the elevation at which the permanent groundwater table (surrounding the disposal area) exists.

23. The sum of vertical subsidence expected from dredged material

desiccation and consolidation will, when multiplied by the area of the disposal site, allow estimation of the approximate volume of additional storage gained by dewatering activities. In addition, the amount of crust created by the dewatering and, if desired, available for borrow and use in perimeter dike raising or other off-site productive uses can be estimated. Removal of this material will create additional disposal volume for placement of future dredged material.

Subsequent lift placement

24. If subsequent lifts of dredged material are to be placed prior to complete dewatering of the existing lift for which dewatering calculations are being made, it should be assumed that the inundated crust will remain essentially at its current thickness. Upon inundation, any existing subcrust from the previous lift should be included in consolidation settlement calculations, with settlement based on the total stress produced in this subcrust layer by the subsequent lift. Necessary equations to be used for this instance are given in paragraphs 55-57.

Consideration of Disposal Area Foundation

25. As a general rule, when soft disposal area foundations exist, most foundation consolidation occurs during and immediately following disposal into the containment area. If the disposal area foundation is composed of relatively stiff cohesive soil or of cohesionless soil, it is doubtful that appreciable consolidation will occur at any time. The amount of soft foundation soil consolidation may be large and thus result in an appreciable gain in available disposal area volume; thus, the normal assumption of neglecting this volume may be overly conservative. A quick analysis can be made by qualified geotechnical engineers to determine if the differential settlement between the interior of the disposal area and the perimeter dikes will contribute significantly to available disposal volume. Alternatively, these considerations are covered properly in previously referenced methodologies.[5,6]

Equations Used in Dewatering Prediction Once Dredged Material Reaches the Decant Point

26. The approximate thickness, in feet, of dredged material at the end of the decant phase H_{dm}, when surface drainage improvement should be initiated, is given by

$$H_{dm} = 27V_{cs} \left\{ \frac{\frac{\%\ \text{sand}}{100} + \left[\left(1 - \frac{\%\ \text{sand}}{100}\right) \frac{w_{cd}}{w_{cs}}\right]}{43{,}560A_{ds}} \right\} \quad (1)$$

where

V_{cs} = volume of channel sediment to be dredged, cu yd

% sand = percentage of sand in the channel sediment

w_{cd} = average water content of the dredged material at the end of the decant phase, percent

w_{cs} = average water content of the channel sediment, percent

A_{ds} = area of the disposal site, acres

In lieu of better data, especially if the calculation is made prior to dredging, w_{cd} may be taken as 1.8 × LL, and Equation 1 may be written as

$$H_{dm} = 27V_{cs} \left\{ \frac{\frac{\%\ \text{sand}}{100} + \left[\left(1 - \frac{\%\ \text{sand}}{100}\right) \frac{1.8LL}{w_{cs}}\right]}{43{,}560A_{ds}} \right\} \quad (2)$$

Effect of evaporative dewatering

27. The estimated water loss, in inches, from evaporative dewatering ΔW is given by the relationship

$$\Delta W = 0.35E_p \quad (3)$$

for saltwater dredged material and by

$$\Delta W = 0.50E_p \tag{4}$$

for freshwater dredged material, where E_p is the Class A Pan Evaporation for the dewatering interval.

28. The depth, in inches, to which the initial thickness of dredged material will be dewatered H_i is given by

$$H_i = \frac{w_{cd}}{w_{cr}} \left[\frac{\Delta W}{\left(\frac{w_{cd}}{w_{cr}} \right) - 1} \right] \left(1 + \frac{1}{0.01 w_{cd} G_s^2} \right) \tag{5}$$

where

w_{cr} = average water content of the dewatered dredged material (crust), percent

G_s = specific gravity of the channel sediment/dredged material solids

In the absence of better data, w_{cd} may be assumed as 1.8 × LL, while w_{cr} may be assumed as 1.2 × PL. In such a case, Equation 5 becomes

$$H_i = 1.5 \frac{LL}{PL} \left[\frac{\Delta W}{\left(1.5 \frac{LL}{PL} - 1 \right)} \right] \left(1 + \frac{1}{0.018 LL G_s^2} \right) \tag{6}$$

29. Vertical subsidence, in inches, of the dredged material surface H_s is computed as

$$H_s = \frac{\Delta W}{1 + \frac{P_{dc}}{100}} \tag{7}$$

where P_{dc} is the percentage of total dewatering volume gain due to the volume of the space between desiccation cracks. In lieu of better data, P_{dc} may be taken as 20 percent, and Equation 7 becomes

$$H_s = \frac{\Delta W}{1.2} \tag{8}$$

30. The crust thickness, in inches, formed by desiccation H_{cr} is given by

$$H_{cr} = H_i - H_s \tag{9}$$

31. The estimated volume gain, in cubic yards, from evaporative dewatering shrinkage V_{gd} is computed by

$$V_{gd} = A_{ds} \Delta W \left(1 - \frac{\%\ \text{sand}}{100}\right) \frac{43{,}560}{12(27)} \tag{10}$$

Effect of increased
<u>effective stress consolidation</u>

32. The average initial effective stress, in pounds (force) per square foot, at the center of the undewatered dredged material (subcrust) layer p_i is estimated as

$$p_i = \left[\frac{G_s(1 + 0.01w_{cd})}{1 + 0.01w_{cd}G_s} - 1\right] \frac{\gamma_w}{12} \left(\frac{H_{dm} - H_i}{2} + H_i\right) \tag{11}$$

where γ_w is the unit weight of salt or fresh water, in pounds (force) per cubic foot. In lieu of better data, w_{cd} may be taken as 1.8 × LL, and Equation 11 becomes

$$p_i = \left[\frac{G_s(1 + 0.018LL)}{1 + 0.018LLG_s} - 1\right] \frac{\gamma_w}{12} \left(\frac{H_{dm} - H_i}{2} + H_i\right) \tag{12}$$

33. The increase in effective stress, in pounds (force) per square foot, from water table lowering Δp is approximated by

$$\Delta p = H_i \gamma_w \tag{13}$$

34. The approximate consolidation settlement, in inches, resulting from increased effective stress H_c is approximated by

$$H_c = \frac{(H_{dm} - H_i)C_c}{1 + 0.01w_{cd}G_s} \log \frac{p_i + \Delta p}{p_i} \tag{14}$$

where C_c is the compression index for the dredged material. If better data are not available, w_{cd} may be taken as 1.8 × LL, and Equation 14 becomes

$$H_c = \frac{(H_{dm} - H_i)C_c}{1 + 0.018LLG_s} \log \frac{p_i + \Delta p}{p_i} \tag{15}$$

35. Additional disposal volume gain, in cubic yards, from subcrust consolidation V_{gc} is computed from

$$V_{gc} = H_c A_{ds} \left(1 - \frac{\%\ \text{sand}}{100}\right) \frac{43{,}560}{12(27)} \tag{16}$$

36. Total settlement, in inches, of the dredged material surface from dewatering H_t is thus

$$H_t = H_s + H_c \tag{17}$$

37. Total disposal area volume gain, in cubic yards, from dewatering V_{gt} is given as

$$V_{gt} = V_{gd} + V_{gc} \tag{18}$$

38. The thickness, in inches, of subcrust remaining to be dewatered H_r is given by

$$H_r = H_{dm} - H_i - H_c \tag{19}$$

39. The volume, in cubic yards, of dredged material available for removal and productive use V_p is estimated as

$$V_p = A_{ds} \left\{ \left[H_{cr} \left(1 - \frac{\%\ \text{sand}}{100} \right) \right] + H_{dm} \frac{\%\ \text{sand}}{100} \right\} \frac{43{,}560}{12(27)} \qquad (20)$$

Equations Used in Subsequent Dewatering Prediction or if a Surface Desiccation Crust Already Exists

40. The percentage reduction in the dredged material subcrust water content from consolidation Δw man be computed by the relation

$$\Delta w = \frac{100H_c}{\left(H_r + H_c\right)G_s} \left(1 + 0.01w_{cd}G_s\right) \qquad (21)$$

where, in lieu of better data, w_{cd} may be taken as 1.8 × LL, or

$$\Delta w = \frac{100H_c}{\left(H_r + H_c\right)G_s} \left(1 + 0.018LLG_s\right) \qquad (22)$$

41. The water content, in percent, of the subcrust after initial dewatering w_{sc} is thus

$$w_{sc} = w_{cd} - \Delta w \qquad (23)$$

or, if w_{cd} is assumed to be 1.8 × LL,

$$w_{sc} = 1.8LL - \Delta w \qquad (24)$$

Effect of evaporative dewatering

42. The thickness, in inches, of subcrust material dewatered by desiccation H_i is given by

$$H_i = \frac{w_{sc}}{w_{cr}} \left(\frac{\Delta W}{\frac{w_{sc}}{w_{cr}} - 1} \right) \left(1 + \frac{1}{0.01 w_{sc} G_s^2} \right) \tag{25}$$

43. Vertical subsidence, in inches, of the disposal area surface H_s is computed in the same manner as for initially undewatered conditions, i.e.,

$$H_s = \frac{\Delta W}{1 + \frac{P_{dc}}{100}} \tag{7bis}$$

or, in lieu of better data,

$$H_s = \frac{\Delta W}{1.2} \tag{8bis}$$

44. Additional crust thickness, in inches, formed by desiccation H_{cr} is given by

$$H_{cr} = H_i - H_s \tag{9bis}$$

45. Volume gain, in cubic yards, from dewatering shrinkage V_{gd} may be computed from the relationship

$$V_{gd} = \left(A_{ds} - A_{sm} \right) \Delta W \, \frac{43,560}{12(27)} \tag{26}$$

where A_{sm} is the area of the sand mound in the disposal area, in acres.

Effect of increased
effective stress consolidation

46. The average initial stress, in pounds (force) per square foot, at the center of the undewatered subcrust p_i is given by

51. Total disposal area volume gain, in cubic yards, from dewatering V_{gt} is given by

$$V_{gt} = V_{gd} + V_{gc} \qquad (18bis)$$

52. The thickness of subcrust, in inches, remaining to be dewatered H_r is given by

$$H_r = H_{sc} - H_i - H_c \qquad (30)$$

It should be noted that H_{dm} from the previous set of dewatering calculations becomes H_{sc} for a subsequent set of calculations.

53. The volume of dredged material, in cubic yards, available for removal and productive use V_p is estimated as

$$V_p = \left[\left(H_{sc} + H_{ci}\right)A_{sm} + \left(H_{cr} + H_{ci}\right)\left(A_{ds} - A_{sm}\right)\right]\frac{43,560}{12(27)} \qquad (31)$$

54. The percentage reduction in the dredged material subcrust water content from consolidation Δw may be estimated by

$$\Delta w = \frac{100H_c}{(H_r + H_c)G_s}\left(1 + 0.01w_{sc}G_s\right) \qquad (32)$$

and a revised subcrust water content (for use in subsequent dewatering calculations) may be obtained by subtracting Δw from the original subcrust water content.

Equations Used in Dewatering Prediction When Subsequent Lifts Are Placed Over Existing Crust and Subcrust

55. If, after dewatering, additional dredged material is placed in the disposal area, inundated dredged material existing in crust form is assumed to undergo negligible change in volume, while any undewatered dredged material remaining below the crust is assumed to consolidate

51. Total disposal area volume gain, in cubic yards, from dewatering V_{gt} is given by

$$V_{gt} = V_{gd} + V_{gc} \tag{18bis}$$

52. The thickness of subcrust, in inches, remaining to be dewatered H_r is given by

$$H_r = H_{sc} - H_i - H_c \tag{30}$$

It should be noted that H_{dm} from the previous set of dewatering calculations becomes H_{sc} for a subsequent set of calculations.

53. The volume of dredged material, in cubic yards, available for removal and productive use V_p is estimated as

$$V_p = \left[\left(H_{sc} + H_{ci}\right)A_{sm} + \left(H_{cr} + H_{ci}\right)\left(A_{ds} - A_{sm}\right)\right]\frac{43,560}{12(27)} \tag{31}$$

54. The percentage reduction in the dredged material subcrust water content from consolidation Δw may be estimated by

$$\Delta w = \frac{100H_c}{(H_r + H_c)G_s}\left(1 + 0.01w_{sc}G_s\right) \tag{32}$$

and a revised subcrust water content (for use in subsequent dewatering calculations) may be obtained by subtracting Δw from the original subcrust water content.

Equations Used in Dewatering Prediction When Subsequent Lifts Are Placed Over Existing Crust and Subcrust

55. If, after dewatering, additional dredged material is placed in the disposal area, inundated dredged material existing in crust form is assumed to undergo negligible change in volume, while any undewatered dredged material remaining below the crust is assumed to consolidate

further under the total stress applied by the new lift. The subcrust water content w_{sc} existing just before new lift placement may be estimated from Equation 32, and the effective stress at the center of the existing subcrust just prior to subsequent disposal can be estimated as the sum of stresses computed from Equations 13 and 27 for previous dewatering consolidation. The summation becomes the new p_i for the subcrust layer.

56. Increase in effective stress, in pounds (force) per square foot, on the existing subcrust layer Δp from subsequent lift placement is given as

$$\Delta p = \frac{H_{dm}\gamma_w}{12} \left[\frac{G_s(1 + 0.01w_{cd})}{1 + 0.01w_{cd}G_s} \right] \tag{32}$$

In lieu of better data for the subsequent lift, w_{cd} may be taken as $1.8 \times LL$, or

$$\Delta p = \frac{H_{dm}\gamma_w}{12} \left[\frac{G_s(1 + 0.018LL)}{1 + 0.018LLG_s} \right] \tag{34}$$

57. Additional existing subcrust consolidation from the subsequent lift may be computed from Equation 28, and additional volume gain may be computed from Equation 29.

Examples of Prediction Equation Use

58. Use of the prediction equations for estimating effects of a 1-year surface drainage improvement program immediately following disposal is illustrated in Figure 2. The results of continuing the dewatering for a second year, followed by subsequent lift placement, are illustrated in Figure 3. Example calculations for predicting the effects of a trenching program started on existing crust are given in Figure 4.

For example purposes, a 100-acre disposal site is available at a location where the average annual Class A Pan Evaporation is 70 in. Channel soundings indicate a sediment volume of 1,100,000 cu yd must be removed during scheduled maintenance dredging activities and placed in the disposal area. Test data on samples of channel sediment indicate the material contains 5 percent sand (grain sizes retained on the U. S. Bureau of Standards No. 200 sieve) and the fine-grained fraction has a liquid limit (LL) of 100, a plastic limit (PL) of 40, a specific gravity of solids G_s of 2.7, a compression index C_c of 0.9, and an average natural water content of 120 percent. The dredging will be conducted in a saltwater environment. The decant point is assumed to be at 1.8 × LL (180 percent water content) and the desiccation crust is assumed to have a water content of 1.2 × PL (48 percent water content).

The first calculation necessary determines the approximate thickness of the dredged material at the end of the decant phase, when dewatering should be initiated, from Equation 2 as

$$H_{dm} = 1{,}100{,}000 \left\{ \frac{\frac{5}{100} + \left[\left(1 - \frac{5}{100}\right) \frac{1.8(100)}{120}\right]}{100(43{,}560)} \right\} 27 = 10.1 \text{ ft}$$

$$= 10 \text{ ft} = 120 \text{ in.}$$

It should be noted that the material may occupy a greater volume and have a greater lift thickness in the disposal area during deposition and initial sedimentation. The estimated H_{dm} is the approximate lift thickness when a thin drying skin begins to form on the surface (see Figure 1). Procedures[5,6] are available for estimating the additional freeboard needed to contain the material during disposal.

Effect of evaporative dewatering

Estimated water loss ΔW during the 12-month period following initiation of the dewatering program is, for saltwater dredging, 35 percent of 70 in., or 70 × 0.35 = 24.5 in. of water (Equation 3). The initial thickness of dredged material dewatered may be approximated by Equation 5 as

$$H_1 = 1.5 \left(\frac{100}{40}\right) \frac{24.5}{\left[1.5\left(\frac{100}{40}\right)\right] - 1} \left[1 + \frac{1}{0.018(100)(2.7)^2}\right] = 36.0 \text{ in.}$$

Thus, 36.0 in. of semiliquid material can be dewatered by evaporative drying in 1 year. Vertical subsidence H_s of the surface is given by Equation 8 as

$$H_s = \frac{24.5}{1.2} = 20.4 \text{ in.} = 20 \text{ in.}$$

while the crust thickness H_{cr} formed by desiccation is given by Equation 9 as

$$H_{cr} = 36.0 - 20.4 = 15.6 \text{ in.} = 16 \text{ in.}$$

Thus, during the year, the dredged material surface should settle 20 in., and 16 in. of crust should be formed as a result of evaporative dewatering. The volume gain from dewatering shrinkage may be estimated by Equation 10 as

$$V_{gd} = 100(24.5)\left(1 - \frac{5}{100}\right) \frac{43{,}560}{12(27)} = 313{,}000 \text{ cu yd}$$

During the year, the disposal site internal water table will drop from the original surface to the base of the crust (i.e., 36 in. below the original surface for this example), causing an increase in effective stress on the subcrust dredged material.

Effect of increased effective stress consolidation

The vertical settlement from increased effective stress may be estimated by use of one-dimensional consolidation relationships. First, the average initial effective stress at the center of the affected subcrust layer is estimated from Equation 12 as

$$p_i = \left\{\frac{2.7\,[1 + 0.018(100)]}{1 + [0.018(100)2.7]} - 1\right\} \frac{64.4}{12} \left(\frac{120 - 36}{2} + 36\right) = 121 \text{ psf}$$

while the increase in effective stress Δp caused by water table lowering is approximated by Equation 13 as

$$\Delta p = \frac{36 \text{ in.}}{12 \text{ in./ft}} (64.4 \text{ pcf}) = 193 \text{ psf}$$

The settlement H_c resulting from this stress increase is approximated by Equation 14 as the relationship

$$H_c = \frac{(120 - 36)0.9}{1 + [0.018(100)2.7]} \log \frac{121 + 193}{121} = 5.3 \text{ in.}$$

giving an additional volume gain from consolidation (Equation 16) of

$$V_{gc} = 5.3(100)\left(1 - \frac{5}{100}\right) \frac{43{,}560}{12(27)} = 68{,}000 \text{ cu yd}$$

The total settlement H_t of the disposal area surface as a result of dewatering is thus, from Equation 17,

$$H_t = 20.4 + 5.3 = 25.7 \text{ in.} = 26 \text{ in.}$$

while the total disposal area volume gain V_{gt} is thus (Equation 18)

$$V_{gt} = 313{,}000 + 68{,}000 = 381{,}000 \text{ cu yd}$$

The thickness of subcrust remaining to be dewatered H_r is given by Equation 19 as

$$H_r = 120 - 36 - 5 = 79 \text{ in.}$$

while the volume of dredged material V_p now available for removal and productive use is given by Equation 20 as

$$V_p = 100 \left\{\left[16\left(1 - \frac{5}{100}\right)\right] + \left[120\left(\frac{5}{100}\right)\right]\right\} \frac{43{,}560}{12(27)} = 285{,}000 \text{ cu yd}$$

Summary

Thus, for the given example, 1,100,000 cu yd of channel sediment was placed in a 100-acre disposal area, having a lift thickness of 10 ft or 120 in. when dewatering was initiated. After 1 year of evaporative dewatering, the surface subsided 26 in., a 16-in.-thick crust was formed, and 381,000 cu yd of additional disposal volume was created in the disposal area. A total of 285,000 cu yd of soil is available for removal and productive use, and 79 in. of essentially undewatered subcrust material remains. For the example channel sediment/dredged material engineering properties and disposal site climatic environment, it should be noted that, if a 36-in.-thick lift had been placed, it would have been completely dewatered in 1 year.

Figure 2. Example illustrating use of prediction equations once fine-grained dredged material reaches the decant point

If dewatering is continued for a second year, another 24.5 in. of water will be removed by evaporative drying. From the previous example (Figure 2), 79 in. of undewatered material remains. Consolidation under increased effective stress will have reduced the average subcrust water content from approximately 1.8 × LL by an amount (Equation 22)

$$\Delta w = \frac{100(5)}{(79 + 5)2.7} \left\{1 + [0.018(100)2.7]\right\} = 13 \text{ percent}$$

such that the previous subcrust water content of 1.8 × LL or 180 percent should be reduced by 13 percent giving a new subcrust water content w_{sc} of 167 percent (Equation 24).

Effect of evaporative dewatering

The thickness of dredged material dewatered may be approximated by Equation 25 as

$$H_1 = \frac{167}{1.2(40)} \left[\frac{24.5}{\frac{167}{1.2(40)} - 1}\right] \left[1 + \frac{1}{0.01(167)2.7}\right] = 37.2 \text{ in.} = 37 \text{ in.}$$

while the vertical subsidence is given by Equation 8 as

$$H_s = \frac{24.5}{1.2} = 20.4 = 20 \text{ in.}$$

and the additional crust thickness H_{cr} formed by desiccation is given by Equation 9 as

$$H_{cr} = 37.0 - 20 = 17 \text{ in.}$$

These results are essentially the same as those obtained during the first year of dewatering; use of Equation 10 indicates 313,000 cu yd of storage created by second-year evaporative drying.

Effect of increased effective stress consolidation

As a result of second-year evaporative drying, the internal disposal area water table will drop another 37 in., to the base of the crust. Stress conditions at the center of the affected subcrust layer at the beginning of the second year may be approximated by Equation 27 as

$$p_1 = \left(\frac{16(64.4)}{12} \left\{\frac{2.7[1 + 0.012(40)]}{1 + [0.012(40)2.7]}\right\}\right) + \left(\left\{\frac{2.7[1 + 0.01(167)]}{1 + [0.01(167)2.7]} - 1\right\}\right.$$

$$\left.\frac{64.4}{12} \left\{\frac{79 - 37}{2} + 37\right\}\right) = 246 \text{ psf}$$

while the increase in effective stress Δp caused by water table lowering is approximated by Equation 13 as

$$\Delta p = \frac{37}{12 \text{ in./ft}} (64.4 \text{ pcf}) = 199 \text{ psf}$$

In this instance, the consolidation settlement H_c is approximated by Equation 28 as

$$H_c = \frac{(79 - 37)0.9}{1 + [0.01(167)2.7]} \log \frac{246 + 199}{246} = 1.8 \text{ in.} = 2 \text{ in.}$$

and the additional volume gain from consolidation V_{gc} from Equation 16 is

$$V_{gc} = 2(100) \left(1 - \frac{5}{100}\right) \frac{43,560}{12(27)} = 26,000 \text{ cu yd}$$

Additional vertical settlement during the second year is given by Equation 17 as

$$H_t = 20 + 2 = 22 \text{ in.}$$

and the disposal volume gained during the second year V_{gt} is given by Equation 18 as

$$V_{gt} = 313,000 + 26,000 = 339,000 \text{ cu yd}$$

while the thickness of subcrust remaining to be dewatered is given by Equation 30 as

$$H_r = 79 - 37 - 2 = 40 \text{ in.}$$

The volume of additional dredged material V_p available for productive use as a result of second-year dewatering is given by Equation 20 as

$$V_p = 100(17) \left(1 - \frac{5}{100}\right) \frac{43,560}{12(27)} = 217,000 \text{ cu yd}$$

Summary

For the given example, 1,100,000 cu yd of channel sediment was placed in a 100-acre disposal area, having a lift thickness of 10 ft or 120 in. when dewatering was initiated. After 2 years of evaporative dewatering, the surface settled 26 in. + 22 in. or 48 in., a crust 16 in. + 17 in. or 33 in. thick was produced, and a total additional disposal volume of 381,000 cu yd + 339,000 cu yd or 720,000 cu yd was created by dewatering. A total of 285,000 cu yd + 217,000 cu yd or 502,000 cu yd of dredged material suitable for productive use is now available. Below the 33-in. crust, approximately 40 in. of essentially undewatered dredged material remains. If the dewatering program was continued for a third year, almost the entire original lift thickness would be dewatered. Third-year results could be estimated by repeating the above calculations and substituting first- plus second-year totals for the first-year data.

Effect of subsequent lift placement

For illustrative purposes, the effect of subsequent lift placement after 2 years of dewatering described in the previous example will be determined. In the above example, 40 in. of undewatered dredged material remains, and second-year consolidation will have reduced the average water content from the end-of-first-year 167 percent by an amount Δw, given by Equation 32 as

$$\Delta w = \frac{100(2)}{(40 + 2)2.7} [1 + 0.01(167)2.7] = 10 \text{ percent}$$

such that the average water content w_{sc} is now 157 percent. The existing effective stress at the center of the affected subcrust (now p_i) after the second year was given previously as 246 psf + 199 psf or 445 psf.

If an additional lift of similar dredged material is placed which is quickly decanted to a 10-ft (120-in.) lift thickness at a water content of 1.8 × LL, the stress change Δp produced by this lift is, from Equation 34,

$$\Delta p = \frac{120}{12} (64.4) \frac{2.7[1 + 0.018(100)]}{1 + [0.018(100)2.7]} = 831 \text{ psf}$$

The additional vertical settlement H_c caused by existing subcrust consolidation may be approximated by Equation 28, when the term $(H_{sc} - H_1)$ is replaced by the existing subcrust thickness remaining, or

$$H_c = \frac{40(0.9)}{1 + [0.01(157)2.7]} \log \frac{445 + 831}{445} = 3.1 \text{ in.} = 3 \text{ in.}$$

Volume gain from this consolidation may be computed from Equation 29.

Figure 3. Example illustrating use of prediction equations in 1-year surface trenching program (Figure 2) past the first year

In a disposal area where evaporative dewatering is not initiated as soon as first-stage drying ends (i.e., the conditions shown in Figure 1), the dredged material may be expected to consolidate very slowly from approximately 1.8 × LL to the LL, and a thin crust may form on the dredged material surface. The amount of volume gain and crust formation expected from a dewatering program initiated under these conditions will depend upon the engineering properties, the existing average water content, and the current crust thickness of the fine-grained dredged material.

For example purposes, assume dredged material with an average liquid limit (LL) of 100, plastic limit (PL) of 40, specific gravity of solids G_s of 2.7, and compression index C_c of 1.0 has been previously placed in an 85-acre disposal area. The specific gravity of fine-grained dredged material solids was found to be 2.7, and the dredging was conducted in a saltwater environment. Below an existing 4-in. crust, 8 ft of subcrust material exists at an average water content of 120 percent. Crust water content w_{cr} is assumed to be 1.2 × PL. A mound of sand around the dredge pipe location occupies approximately 5 acres of the site. Average annual Class A Pan Evaporation at the disposal site is 65 in.

Effect of evaporative dewatering

The amount of water removed, from Equation 3, ΔW is 65 in. × 0.35 or 22.8 in., and the depth of drying below the existing crust is approximated by Equation 25 as

$$H_i = \frac{120}{1.2(40)} \left[\frac{22.8}{\frac{120}{1.2(40)} - 1} \right] \left[1 + \frac{1}{0.01(120)\ 2.7^2} \right] = 42 \text{ in.}$$

while the vertical subsidence is given by Equation 8 as

$$H_s = \frac{22.8}{1.2} = 19 \text{ in.}$$

and the additional crust thickness H_{cr} formed is given by Equation 9 as

$$H_{cr} = 42 - 19 = 23 \text{ in.}$$

The volume gain from dewatering shrinkage V_{gd} may be estimated by Equation 26 as

$$V_{gd} = (85 - 5)(22.8)\ \frac{43,560}{12(27)} = 245,000 \text{ cu yd}$$

Effect of increased effective stress consolidation

The saline water table, initially assumed to be at the base of the existing 4-in. crust, will drop an additional 42 in., increasing effective stress on the subcrust. The crust water content is taken as 48 percent (1.2 × PL). The initial effective stress at the center of the affected subcrust layer is given by Equation 27 as

$$p_i = \left(\frac{4(64.4)}{12} \left\{ \frac{2.7[1 + 0.01(48)]}{1 + [0.01(48)2.7]} \right\} \right) + \left(\left\{ \frac{2.7[1 + 0.01(120)]}{1 + [0.01(120)2.7]} - 1 \right\} \frac{64.4}{12} \left\{ \frac{96 - 42}{2} + 42 \right\} \right) = 186 \text{ psf}$$

while the increase in effective stress Δp is given by Equation 13, or

$$\Delta p = \frac{42 \text{ in.}}{12 \text{ in./ft}} (64.4 \text{ pcf}) = 225 \text{ psf}$$

The resulting settlement H_c is given by Equation 28 as

$$H_c = \frac{(96 - 42)1.0}{1 + [0.01(120)2.7]} \log \frac{186 + 225}{186} = 4.4 \text{ in.} \approx 4 \text{ in.}$$

causing an additional volume gain from consolidation (Equation 29) of

$$V_{gc} = 4(85 - 5)\ \frac{43,560}{12(27)} = 43,000 \text{ cu yd}$$

The total settlement H_t of the disposal area surface is given by Equation 17 as

$$H_t = 19 + 4 = 23 \text{ in.}$$

while the total disposal volume gain V_{gt} is given by Equation 18 as

$$V_{gt} = 245,000 + 43,000 = 288,000 \text{ cu yd}$$

The thickness of subcrust remaining to be dewatered H_r is given by Equation 19 as

$$H_r = 96 - 42 - 4 = 50 \text{ in.}$$

while the volume of dredged material V_p now available for productive use (including the sand mound and existing crust) is approximated by Equation 31 as

$$V_p = \left\{ [(96 + 4)5] + [(23 + 4)(85 - 5)] \right\} \frac{43,560}{12(27)} = 358,000 \text{ cu yd}$$

Summary

For the given example, 96 in. of semiliquid dredged material below a 4-in. existing crust was dewatered to an additional depth of 42 in. in 1 year, producing a 23-in. vertical subsidence of the dredged material surface. An additional 23 in. of crust was produced, giving a total crust thickness of 27 in. For the given 85-acre disposal site, 288,000 cu yd of additional disposal volume was gained and a total of 358,000 cu yd of material is available for productive use. An undewatered subcrust 50 in. thick remains, and a second year of dewatering would almost completely dewater the example disposal area. Second-year effects may be estimated by repeating the above calculations with first-year results as input values.

Figure 4. Example illustrating use of prediction equations for case where surface crust is present

Improvement of Disposal Area Surface Drainage--Passive Phase

59. Once the disposal operation is completed, dredged material usually undergoes hindered sedimentation and self-weight consolidation (called the "decant phase"), and water will be brought to the surface of the consolidating material at a faster rate than can normally be evaporated. During this phase, it is extremely important that continued drainage of decant water and/or precipitation through outlet weirs be facilitated. Weir flowline elevations may have to be lowered periodically as the surface of the newly placed dredged material subsides. Guidelines for appropriate disposal site operation during this passive dewatering phase, to maximize decant and precipitation water release while maintaining appropriate water quality standards, are available elsewhere.[6]

60. Once the fine-grained dredged material approaches the decant point water content, the rate at which water is brought to the surface will gradually drop below the climatic evaporative demand. If precipitation runoff through site outflow weirs is facilitated, a thin drying crust or skin will form on the newly deposited dredged material. The thin skin may be only several hundredths of a foot thick, but its presence may be observed by noting small desiccation cracks which begin to form at 3- to 6-ft intervals, as shown previously in Figure 1. Once the dredged material has reached this consistency, active dewatering operations may be initiated.

Improvement of Disposal Area Surface Drainage--Initial Active Phase

61. Three procedures have been found viable to initiate active dredged material dewatering by improved surface drainage, once the material has achieved consistency conditions shown in Figure 1:

a. Periodic perimeter trenching by dragline, with draglines working initially from perimeter dikes and subsequently from berms established inside the perimeter dikes.

b. Periodic interior site trenching by the Riverine Utility Craft.

c. Combination of procedures a and b above.

This section presents information necessary to properly conduct dewatering operations by the procedures. Only procedures b and c will result in total site dewatering at the maximum rates predicted in previous sections. Procedure a would have, in many instances, an effective interior dewatering rate considerably less than the predicted maximum rate, though the exact lower rate would be highly site-specific.

Periodic dragline trench dewatering

62. Dragline construction of trenches around the inside perimeter of confined disposal sites is a procedure that has been used for many years to dewater and/or reclaim fine-grained dredged material. In many instances, the purpose of dewatering has been to obtain convenient borrow for use in perimeter dike raising activities. Draglines have been found to be highly adaptable to such activities because of their relatively long boom length, while hydraulically operated backhoes have not, primarily because of their limited reach.

63. Initial trenching from the perimeter dike. When initiating dragline trenching operations, the largest size, longest boom length dragline which may be transported efficiently to the disposal site and can operate efficiently on top of disposal site dikes is obtained. In many instances, the largest allowable dragline may be a relatively small one such as a Bucyrus-Erie Model 15B with 35- to 40-ft boom. The dragline is moved to the site and climbs onto the perimeter dike, using mats if necessary to provide necessary mobility. Criteria relating dragline mobility to soil strength conditions, applicable either on perimeter dikes or in confined disposal areas, are given elsewhere[11,12] and will be summarized later. Operations are begun at an outflow weir location, where the dragline, operating from the perimeter dike, digs a sump around the weir extending into the disposal area to maximum boom and bucket reach. The very wet excavated material is cast against the

interior side of the adjacent perimeter dike. It may be necessary to board up the weir to prevent the very wet dredged material from falling into the weir box during the sump-digging operation. Because of the very wet and fluid consistency of the dredged material beneath the thin drying skin, a deep sump may not be constructed initially; however, continued digging will result in a localized low spot some 1 or 2 in. in elevation below the surrounding dredged material. Once the sump has been completed, weir boards should be removed down to the level of the dredged material, and, if necessary, handwork should be conducted to insure that any water flowing into the sump depression will exit through the outflow weir.

64. Once the sump has been completed, the dragline then moves along the perimeter dike, casting its bucket the maximum practicable distance into the disposal area, dragging material back in a wide shallow arc to be cast on the inside of the perimeter dike. Again, the fluid nature of the dredged material will not allow construction of deep trenches, the cast material will stand on only an extremely shallow (1V on 10H or less) slope, and it will be extremely difficult to get more than approximately one fourth to one half of a full bucket with each swing. However, it is not necessary that the dragline remove large quantities of material at any given location during this initial attempt; instead, only a wide shallow depression 1 or 2 in. lower than the surrounding dredged material is desired. For this reason, the dragline should make only one or two long shallow casts at a given spot along the trench before moving over one bucket width to dig the adjacent part of the trench. If the normal tendency of the dragline operator to continually dig material at a single location is countermanded by proper direction, a small dragline should be able to accomplish between 200 and 400 linear ft of trenching per working day, depending upon the mobility of the dragline on the perimeter dike. This extremely shallow trenching proceeds to the next outflow weir where another sump is constructed, and so on around the disposal area perimeter.

65. Trenches produced by this initial work (Figure 5) will be only slightly below the surface of the interior dredged material, but a small

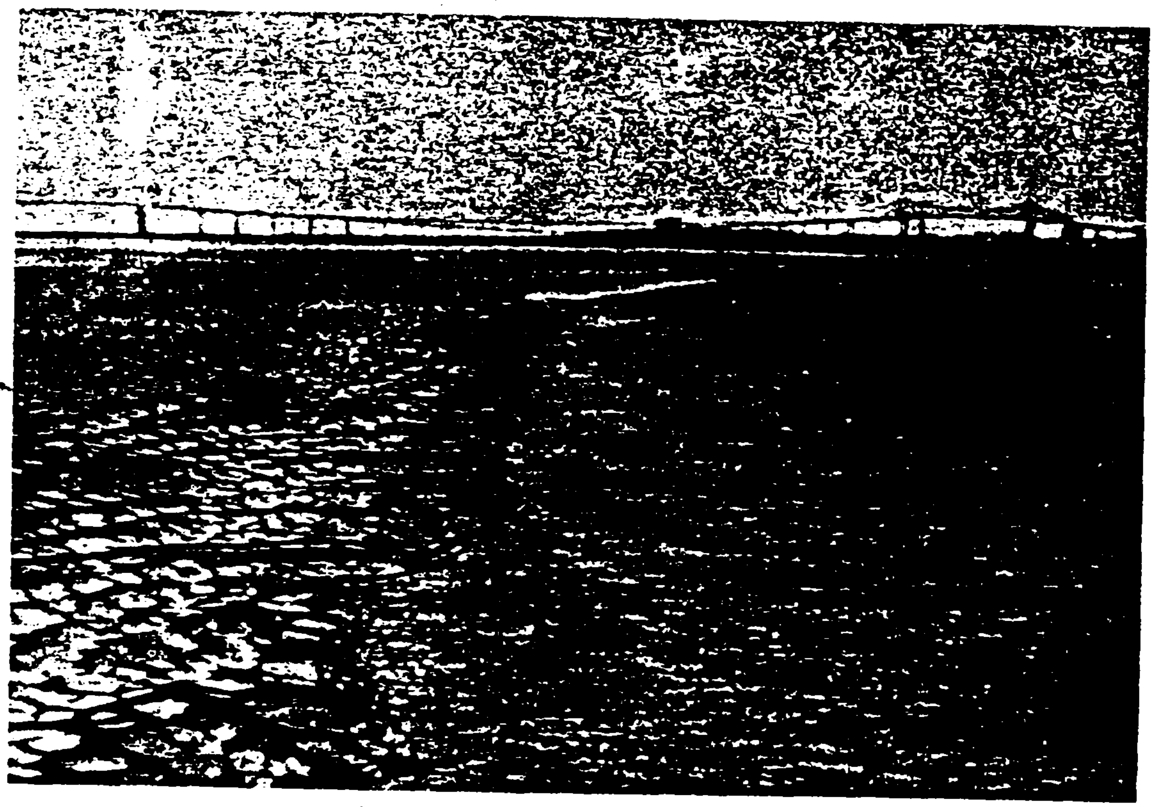


Figure 5. Shallow initial perimeter trench constructed by dragline operating from perimeter dike

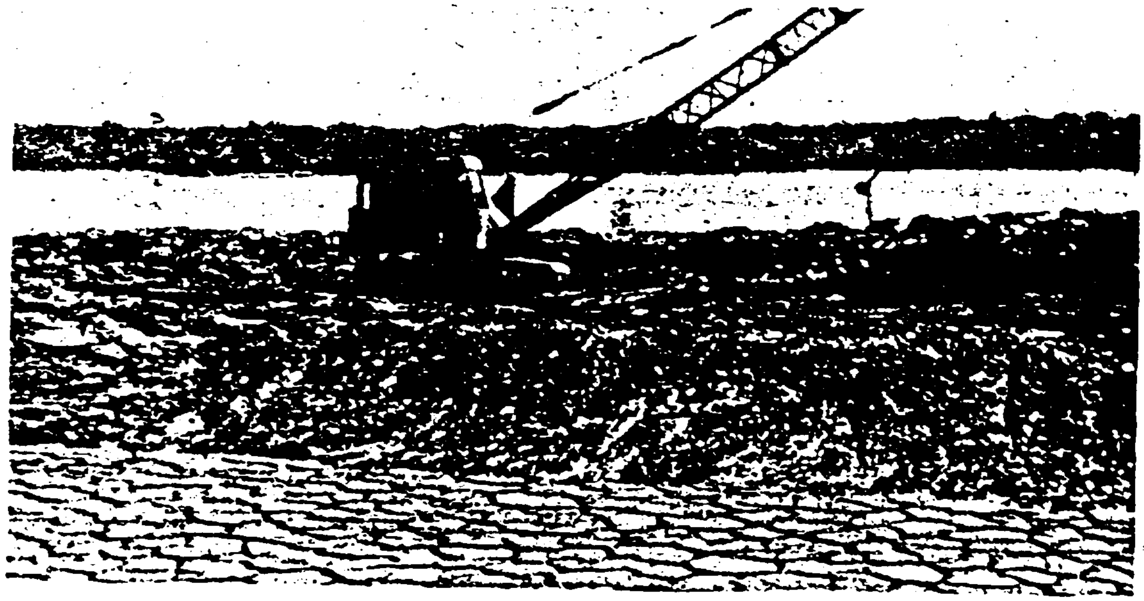
elevation difference is enough to channel precipitation to the perimeter ditches and down the perimeter ditches to the outflow weirs. Also, because of the ditch proximity, dredged material near the ditch edge will tend to dry slightly faster than material located farther out in the disposal site, with resulting dredged material shrinkage giving a slight elevation gradient from the site interior toward the perimeter trenches, also facilitating drainage. Desiccation crack formation will also be more pronounced near the drainage trenches, facilitating precipitation runoff through the cracks to the perimeter trenches.

66. Subsequent trenching from the perimeter dike. Once appreciable desiccation drying has occurred in the dredged material adjacent to the perimeter trench and the material cast on the interior slope of the perimeter dike has dried, the perimeter trenches and weir sumps should be deepened. The exact time between initial and secondary trench deepening will vary according to engineering properties of the dredged

material and existing climatological conditions, ranging from 2 or 3 weeks during hot, dry summer months up to 8 or 10 weeks in colder, wetter portions of the year. Inspection of existing trenches is the most reliable guideline for initiating new trench work, since desiccation cracks 1 or 2 in. deep should be observed in the bottom of existing trenches. Depending on the size of the disposal area, relative costs of mobilization and demobilization of dragline equipment, and the relative priority and/or need for dewatering, it may prove convenient to employ one or more draglines continuously over an interval of several months to periodically work the site. A second trenching cycle should be started upon completion of an initial cycle, a third cycle upon completion of the second cycle, etc., as needed.

67. During the second trenching cycle, the initial cycle procedure is again followed, with careful field inspection to keep the draglines from digging too long at a given location. The excavated material is cast on the interior slope of the perimeter dike, on top of previously excavated material. During the second trenching, wide shallow trenches with a maximum depth of 2 to 6 in. below the surface of adjacent dredged material can be constructed, and sumps can be dug to approximately 8 to 12 in. below surrounding dredged material. These deeper trenches will again facilitate more rapid dewatering of dredged material adjacent to their edges, with resulting shrinkage and deeper desiccation cracks providing a still steeper drainage flow gradient from the site interior to the perimeter trenches.

68. <u>Trenching from interior berms.</u> After two or perhaps three complete periodic perimeter dragline trenching cycles, the next phase of the trenching operation may be initiated. In this phase, the dragline takes the now dry material placed on the interior of the perimeter dike and spreads it to form a low berm adjacent to the dike inside the disposal area. The dragline then moves onto this berm, using single or double mats if required, and, using the increased digging reach now available, widens and extends the ditch into the disposal site interior, as shown in Figure 6a. The disposal site side of the ditch is composed of material previously dried, and a ditch 12 to 18 in. deep may be



a. Small dragline on mats working on berm deepens shallow perimeter drainage trench

b. Deepened perimeter trench constructed by dragline working on berm

Figure 6. Trenching from berm inside perimeter dike

constructed, as shown in Figure 6b. Material excavated from this trench is again cast on the interior slope of the perimeter dike to dry and be used either to raise the perimeter dike or for subsequent berming farther into the disposal area.

69. In order to predict whether or not draglines and other equipment can operate successfully on perimeter dikes, on interior berms composed of dewatered dredged material, or inside disposal sites, criteria have been developed[12] relating vehicle ground pressure, with or without mats, and rating cone index (RCI) of the supporting soil, as shown in Figure 7. The RCI can be obtained rapidly in the field by one or two technicians by hand-pushing a small cone penetrometer through the soil and determining the resistance to penetration. (Under some conditions field penetration resistance data for remolded material must also be determined.) The critical layer RCI is the lower of the 0- to 6-in. or 6- to 12-in. layer resistance values encountered in the field, for, if the dragline (or other type of vehicle on equipment) breaks through these layers, soil strength usually decreases even further and the vehicle will become immobilized. Caution should be exercised when selecting a vehicle whose ground pressure just equals that obtained from Figure 7 for the available RCI, to allow for undetected soft spots in the area or possible vehicle operation errors that could cause immobilization. Engineer Manual 1110-2-5000[12] should be consulted for more exact procedures.

70. Effects of trenching. Once the dragline has moved onto the interior berms to continue the periodic trench deepening operation, criteria are also available, as shown in Figure 8, to predict the rate at which trenching operations may be conducted. In this figure, which shows linear trenching in feet per hour plotted versus RCI, the RCI is for the soil supporting the dragline. The relationships in Figure 8 are, at this stage, based on limited data. However, in the absence of better data, they may be used for approximate preliminary estimates of expected behavior. A more detailed discussion of these relationships is available elsewhere.[11,12] After two or more additional periodic trench deepenings, working from the berm inside the disposal area, trenches up

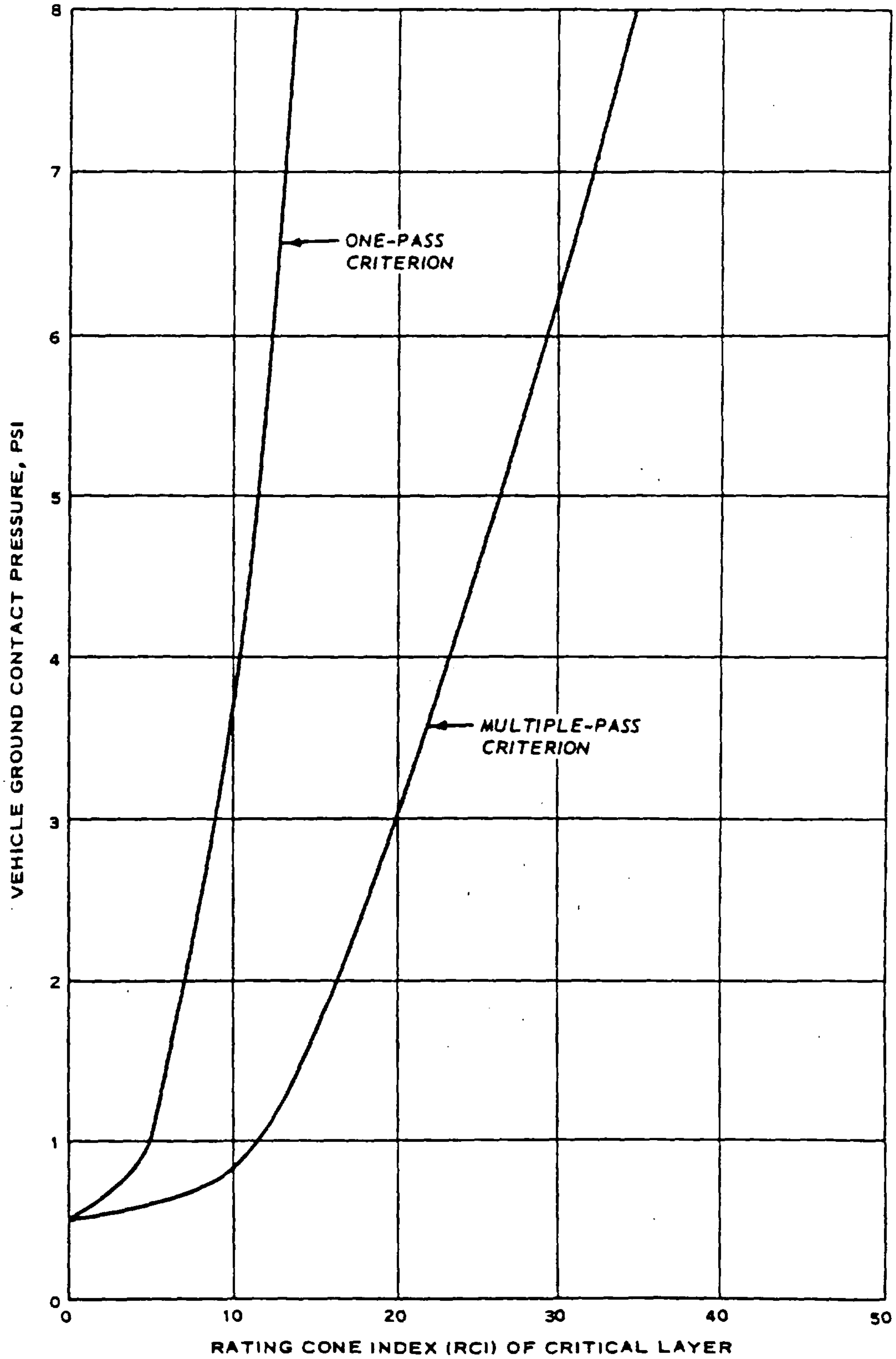


Figure 7. Relationship between RCI necessary to insure adequate mobility and vehicle ground pressure for single- and multiple-pass operations in confined dredged material disposal areas

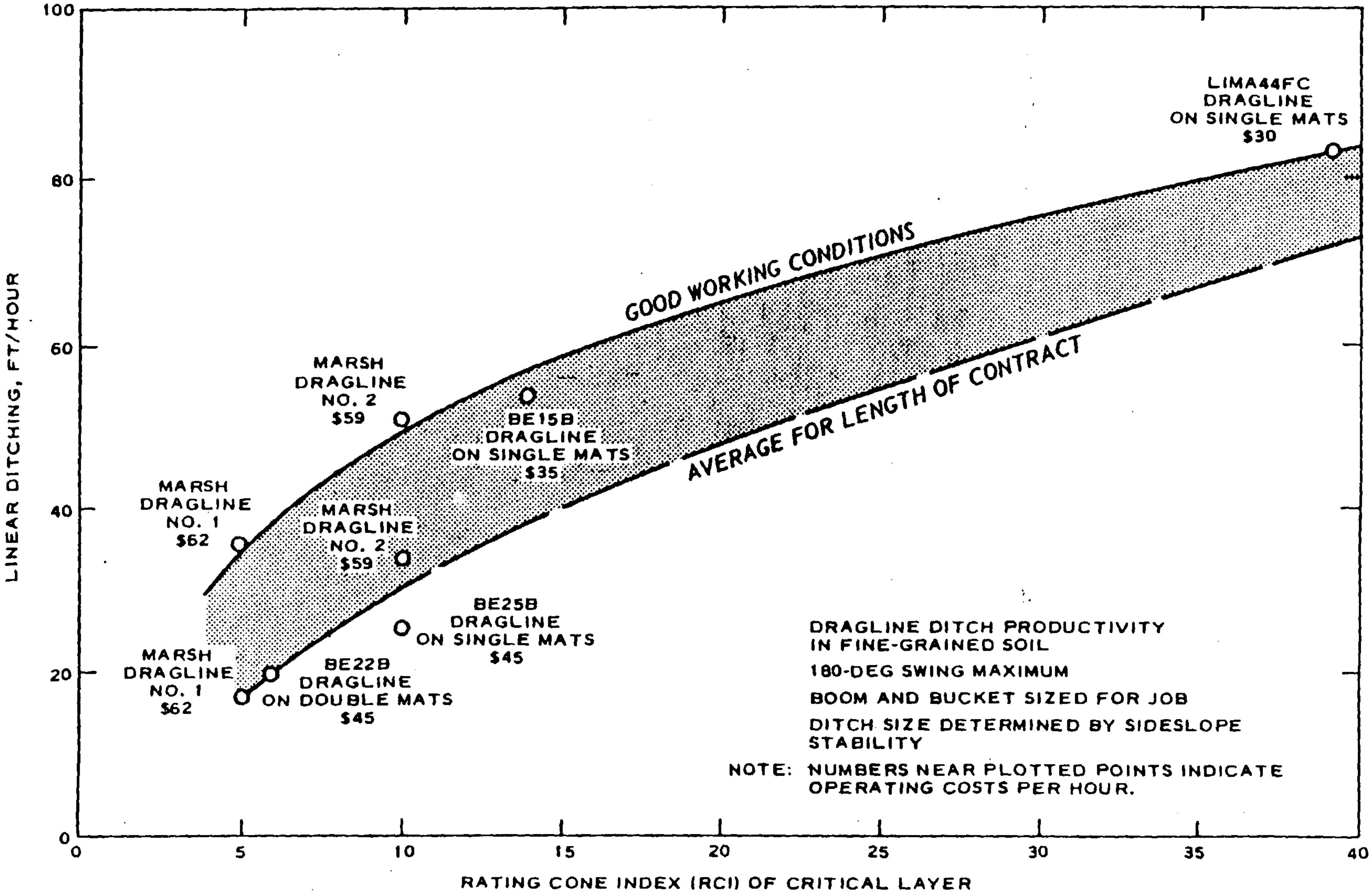


Figure 8. Relationship between RCI of confined disposal area surface crust and linear trenching rate obtainable by dragline equipment

to 3 to 5 ft deep may be completed. Trenches of this depth will cause accelerated drying of the dredged material adjacent to the trench and produce desiccation cracks extending almost the entire thickness of the adjacent dredged material, as shown in Figure 9. A well-developed perimeter trench network leading to outflow weirs is now possible, as shown in Figure 10, and precipitation runoff is facilitated through gradual development of a network of desiccation cracks which extend from the perimeter trenches to the interior of the site.

71. Once a perimeter trench system such as that shown in Figure 10 is established, progressive deepening operations should be conducted at less frequent intervals, and major activity should be changed from deepening perimeter trenches and weir sumps to that of continued inspection to make sure that the ditches and sumps remain open and facilitate free drainage. As a desiccation crack network propagates from the perimeter of the site toward the site interior, with the cracks becoming wider and deeper, precipitation runoff rate will be increased and precipitation ponding in the site interior will be reduced. As such ponding is reduced, more and more evaporative drying will occur, and the desiccation crack network will propagate toward the disposal area interior. Figure 10 is a view of the 500-acre Morris Island Disposal Site of the Charleston District, where a 3-ft lift of dredged material was dewatered down to approximately a 1.7-ft thickness at the perimeter over a 12-month period by an aggressive program, undertaken by the District, of site drainage improvement with dragline perimeter trenching. Figure 11 shows the 12-in. desiccation crust achieved at a location approximately 200 yd from the disposal area perimeter. The dredged material was a CH clay with an LL over 100. However, despite the marked success with perimeter trenching, a close inspection of Figure 10 shows that ponded water still exists in the site interior.

72. Disadvantages of dragline trenching. Once the crust thicknesses obtainable after approximately a 4- to 6-month perimeter trenching program have been achieved, it is usually possible to extend trenches into the disposal site interior, as described subsequently. However, disadvantages and constraints may exist relative to operation of an

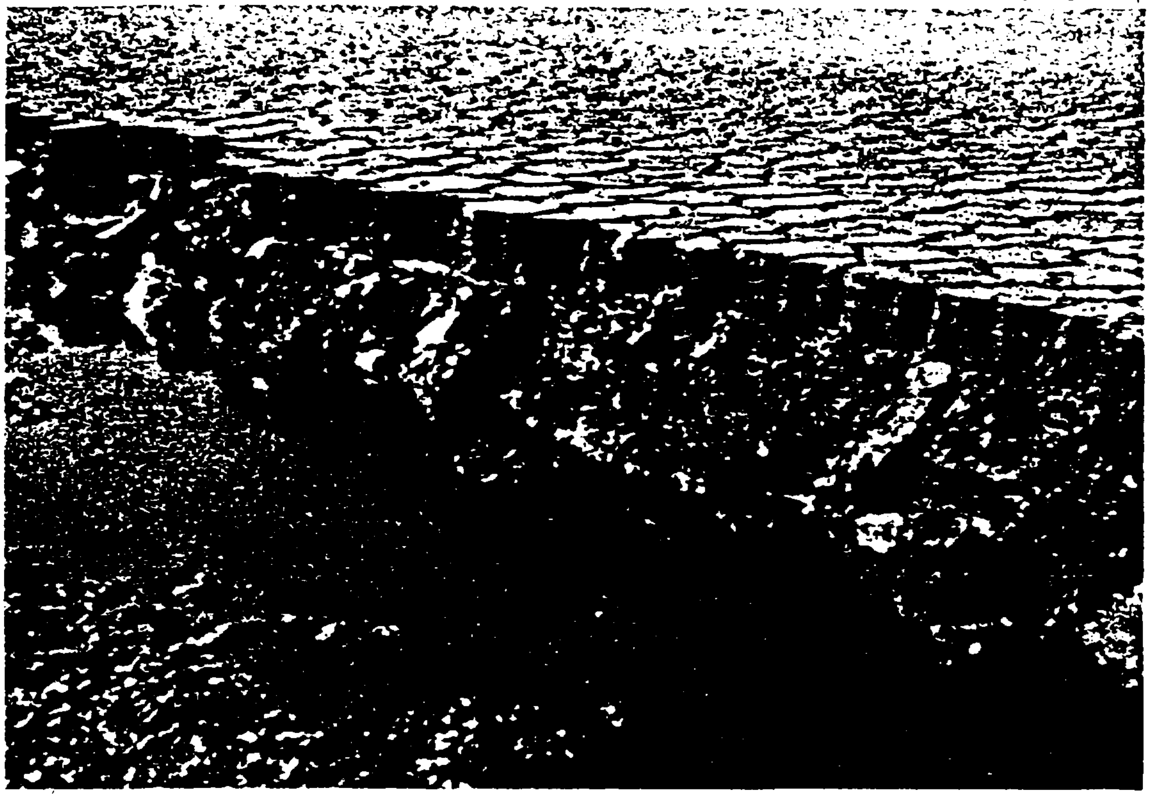


Figure 9. Desiccation crust adjacent to perimeter 3.5-ft-deep drainage trench

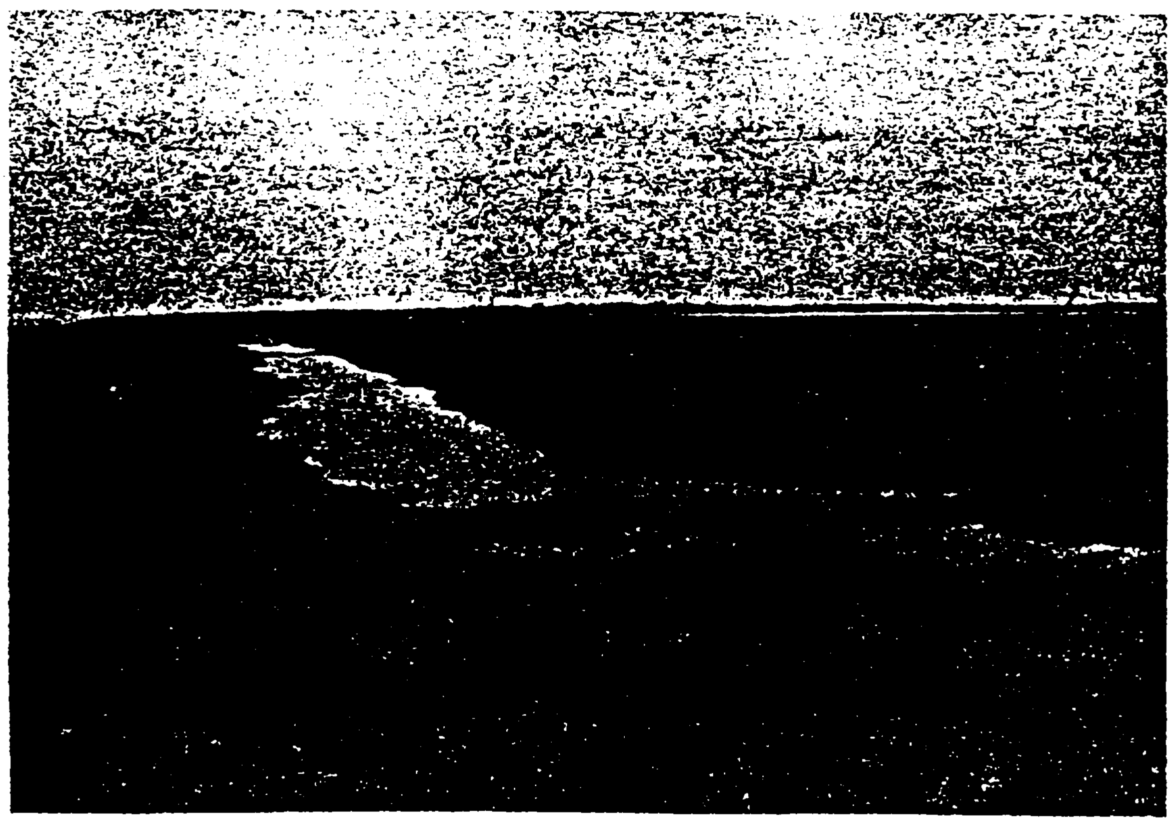


Figure 10. A well-developed perimeter trenching system

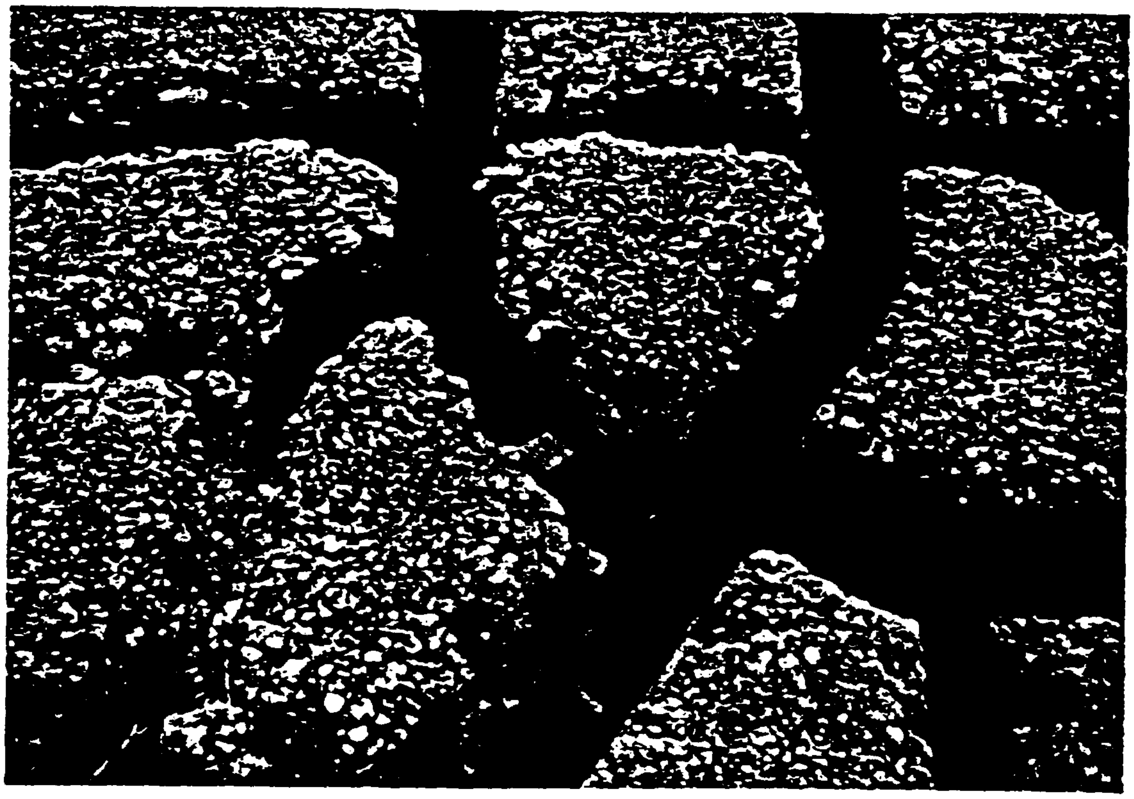


Figure 11. Desiccation crust achieved in highly plastic clay dredged material 200 yd into disposal area by perimeter trenching over 12-month period

active and continuous program of dragline perimeter trenching. Many disposal sites are located in areas so remote that it is difficult to move equipment to them; thus, barge transport may be required and mobilization/demobilization costs high. Further, many perimeter dikes may have inadequate crest width and/or stability to support dragline equipment without causing dike failure. Also, speed of trench construction is relatively slow, and, in many instances, draglines may spend more time in maintaining mobility than in trench construction. Further, unless careful planning is used and the mobility criteria of Figure 7 followed, dragline equipment may become immobilized, with resulting time loss. Finally, depending upon the particular disposal site location and dredging schedule, results produced by the perimeter trenching operation may not cause the desired maximum rate of dredged material dewatering, particularly in the site interior, to make the dewatering operation practical. This problem is often compounded if the disposal area is constructed on soft foundation, as foundation settlement will produce a saucer-shaped center depression and relatively deep perimeter trenches will be required to allow gravity flow of ponded interior surface water to the site perimeter.

73. Some of these constraints may be overcome by beginning site interior trenching as soon as the dredged material reaches the decant point, producing a crust of sufficient thickness to initiate final active phase dewatering operations without need for intermediate operations. This sequence of operations is described in the next section.

Riverine Utility
Craft trench dewatering

74. The earliest possible time for practical initiation of dewatering by improved surface drainage via drainage trenches is when the freshly deposited dredged material has formed a thin surface desiccation skin, as shown previously in Figure 1. At this stage of dredged material consistency, two main deterrents exist to construction of an interior trench drainage network:

a. The fluid consistency of the dredged material below the thin drying skin prohibits trench construction to any significant depth.

b. The essentially zero soil support capacity prohibits conventional low-ground-pressure construction equipment from entering the disposal area to construct the trenches.

These limitations, especially item b, resulted in empirical development of the dragline perimeter trenching procedure described previously. While this technology is successful, an improvement in the rate of dredged material dewatering is possible.

75. Description of the Riverine Utility Craft. The Riverine Utility Craft (RUC) is the most, if not the only, suitable vehicle for use in thinly crusted disposal areas.[12,13] A photograph of the craft is shown in Figure 12, and general RUC specifications are given in Figure 13. Twin Styrofoam-filled rotors support the vehicle and provide flotation in water or on extremely soft ground. The rotors are fitted with double helical blades, and propulsion is accomplished by rotation

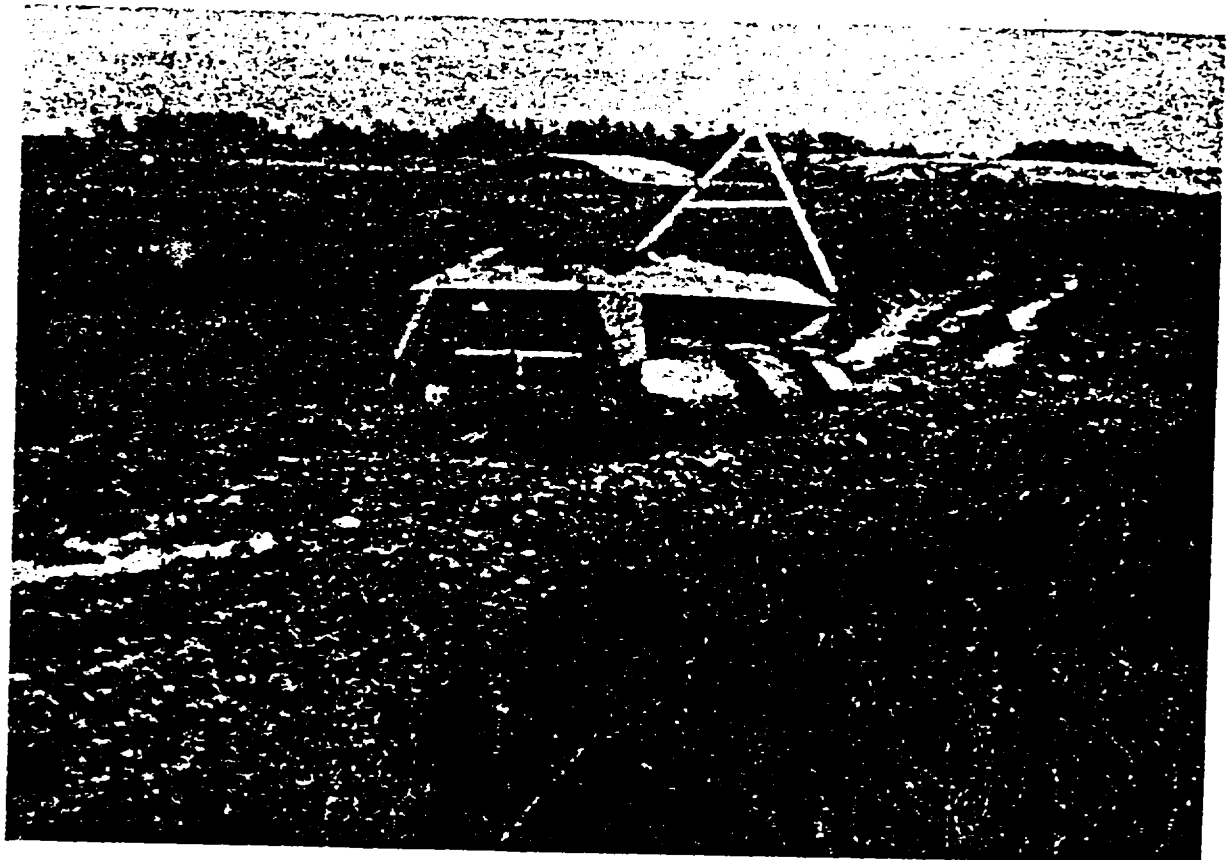
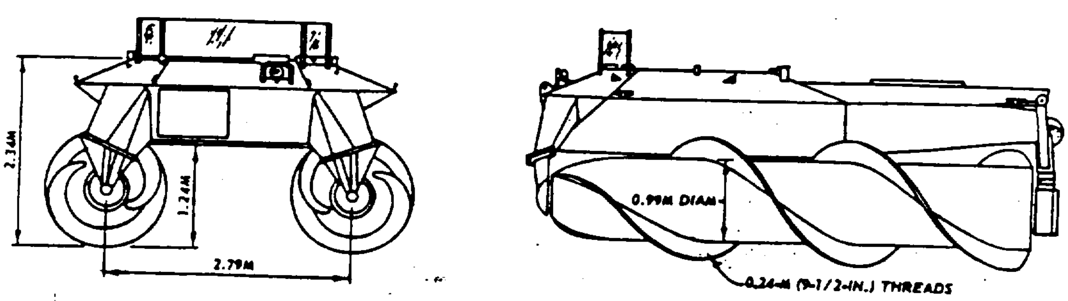


Figure 12. The Riverine Utility Craft or RUC



RIVERINE UTILITY CRAFT		
EMPTY WEIGHT (INCLUDING DRIVER AND FUEL)	4990 KG	(11,000 LB)
GROSS WEIGHT (DRIVER, FUEL AND PAYLOAD)	5900 KG	(13,000 LB)
LENGTH (OVERALL)	6.25 M	(21.5 FT)
WIDTH (OVERALL)	4.27 M	(14 FT)
HEIGHT (OVERALL, LESS WINDSHIELD)	2.34 M	(7.67 FT)
ROTOR SPACING (CENTER TO CENTER)	2.79 M	(110 IN.)
ROTOR DIAMETER (DRUM ONLY)	0.99 M	(39 IN.)
ROTOR DIAMETER (OVER HELIX)	1.47 M	(58 IN.)
ROTOR LENGTH (OVERALL)	5.64 M	(222 IN.)
ROTOR LENGTH (IN CONTACT WITH GROUND, NO RUT)	4.95 M	(195 IN.)
GROUND CLEARANCE	1.24 M	(49 IN.)
FLOATING DEPTH (EMPTY) (WATER)	0.55 M	(21.6 IN.)
FLOATING DEPTH (LOADED) (WATER)	0.61 M	(24 IN.)

Figure 13. General specifications for the RUC

of the rotors in opposite directions. Lateral movement is possible by rotation of both rotors in the same direction. Forward or reverse motion of the vehicle on soft soil causes ruts to be formed by the twin archimedean screws, as shown in Figure 14. If properly placed in the disposal area, these ruts may serve as effective drainage trenches. Additional data concerning uses and performance of the RUC within dredged material disposal areas are available elsewhere.[1,11,12]

76. RUC trenching procedure in newly deposited dredged material. The depth of RUC-constructed trenches varies with fine-grained material crust thickness and consistency. During initial trenching operations after a thin skin, such as that shown in Figure 1, has formed, ruts are wallowed into the wet material, which tends to flow back into and fill the ruts after vehicle passage, giving two shallow depressions rather than distinct ruts (Figure 15). These indistinct shallow depressions will be formed by RUC passage until a crust thickness of approximately

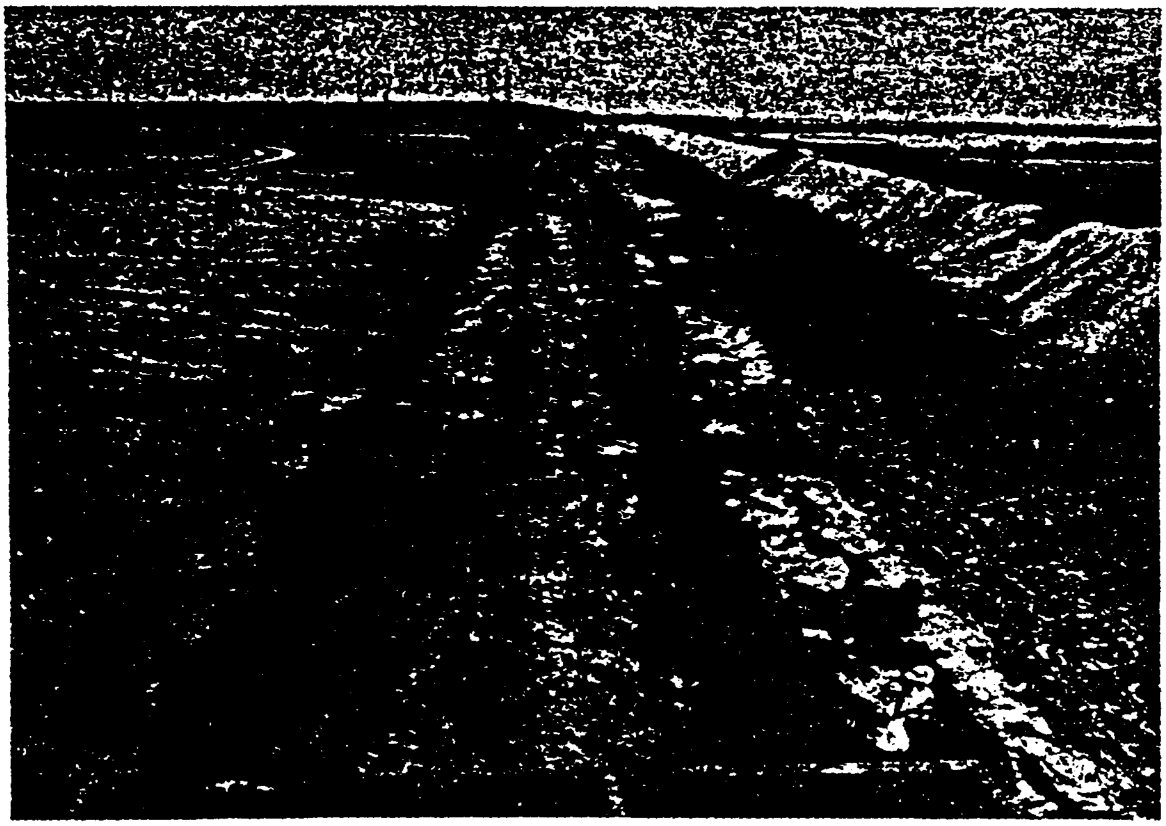


Figure 14. Twin ruts formed in disposal area surface crust by passage of the RUC

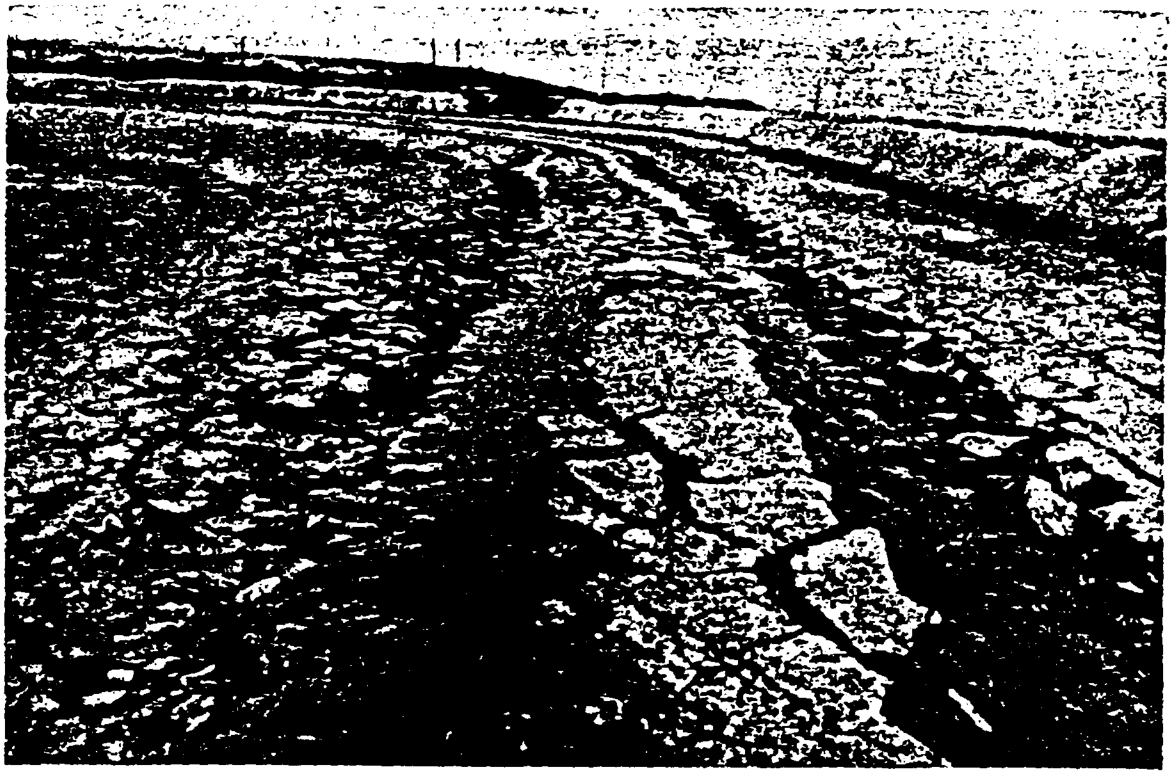


Figure 15. Twin shallow depressions created by the RUC in disposal area surface when a thin surface desiccation skin is present

2 in. is achieved by desiccation. The ruts shown in Figure 15 are only approximately 1/4 in. deeper than the surrounding dredged material. However, this slight elevation difference is sufficient to cause precipitation runoff from the relatively flat dredged material surface into the depressions, and down the trenches to the outlet weirs.

77. Initial RUC trenching is begun by swimming the vehicle in the fluid dredged material to an outflow weir located on the site perimeter. The weir is boarded up to prevent dredged material egress, and the RUC noses up to the weir and pivots in place several times, wallowing out a shallow depression or sump area, as shown in Figure 16. Alternatively, this sump area may be dug with conventional draglines. Once the sump has been constructed, weir stop logs are then removed down to the level of the dredged material surface, and any handwork (with hoes) necessary to insure effective drainage over the weir is carried out, normally by the two-man RUC operating crew. Once the sump is completed, the RUC then makes trenches out into the disposal area from the sump, causing surface drainage down the RUC trenches, into the sump, and over the

Figure 16. Collector sump wallowed in front of outflow weir by pivoting the RUC in place several times

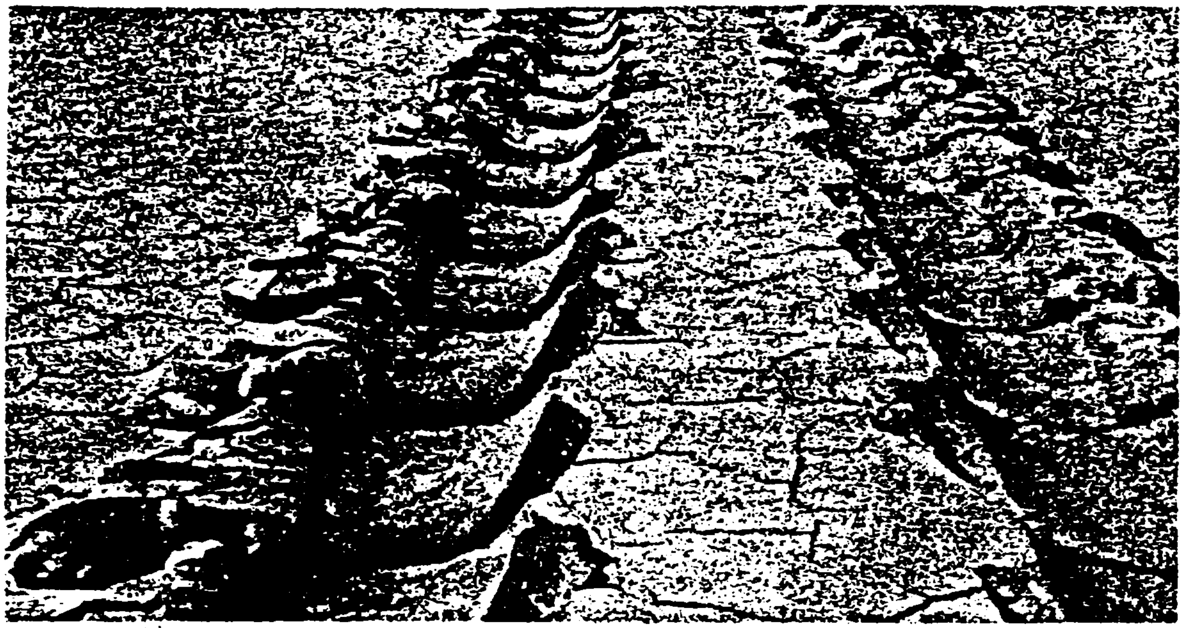
outflow weir. The pattern is repeated at other outflow weirs with, as a minimum, enough trenches constructed by the RUC to effectively drain the disposal site. Optimum craft trenching speed is on the order of 3 to 5 mph, despite the relatively high maximum swim speed (25 mph) of the RUC. Higher speed operation usually causes the RUC rotors to throw material back into the ruts. Nevertheless, at this relatively low speed, it is still possible to effectively trench some 250 to 500 acres per working day, depending upon disposal site configuration, dredged material consistency, and trench spacing desired. Detailed information on proper trench configuration and spacing will be given later.

78. Once initial RUC trenching of the disposal site has been carried out, operations should be temporarily halted to allow drainage of any surface water from the disposal area and allow the shallow depressions formed by RUC passage to desiccate and dry. After this interval, usually 1 to 3 weeks, depending upon climatic conditions, a second traverse of the trenches is made by the RUC, producing further deepening of the trenches. As the crust thickness approaches 2 in., better

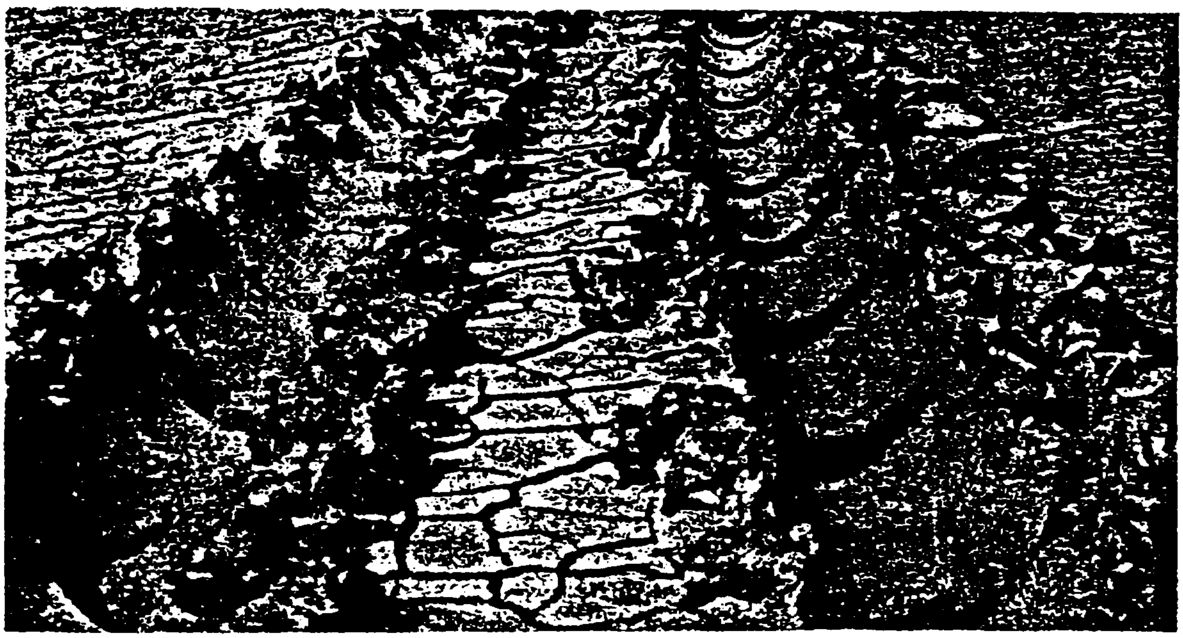
defined trenches will be constructed, as shown in Figure 17. After the trenches desiccate, a third RUC trenching of the area may be carried out, etc.

79. Optimum RUC trenching conditions. As the crust thickness approaches 3 to 5 in., trenches will become better defined, and, when the crust thickness reaches optimum trenching thickness (on the order of 4 to 8 in.), two passes will be necessary to produce a well-defined trench. The first pass serves to break through the crust (Figure 18a), while the second pass completes the trench construction (Figure 18b). Once the dredged material has reached this consistency, trench depths of 4 to 8 in. below the bottom of adjacent crust may be constructed. Also, once the dredged material reaches this consistency, the trenches may be extended directly to outflow weirs without need for sump construction, and deep enough depths will be produced to drain entrapped surface water from low-lying pockets in the disposal area. At this optimum

Figure 17. Drainage trenches produced by the RUC when surface desiccation crust is approximately 2 in. thick



a. First trenching pass



b. Second and final trenching pass

Figure 18. Drainage trenches formed by the RUC in 4- to 8-in.-thick surface crust

trenching stage, the interval between periodic RUC trenching may be expanded to 4 to 6 weeks, again depending upon existing climatic conditions. Drying will occur in the dredged material between RUC trenches, forming a crack network draining into the RUC trenches, as shown in Figure 19. It is also possible that precipitation leaching of salts from the dried material will allow establishment of freshwater vegetation, enhancing site aesthetics.

80. Operational limit of RUC trenching. Periodic RUC deepening of existing trenches should be carried out at 4- to 6-week intervals, until a trench depth of approximately 18 in. below surrounding crust is achieved. This trench depth represents the approximate operational limit of RUC trenching performance and should be reached after approximately 4 to 6 months of periodic RUC trenching, depending upon existing climatic conditions and dredged material engineering properties. During this interval, a surface crust on the order of 12 to 15 in. should have been

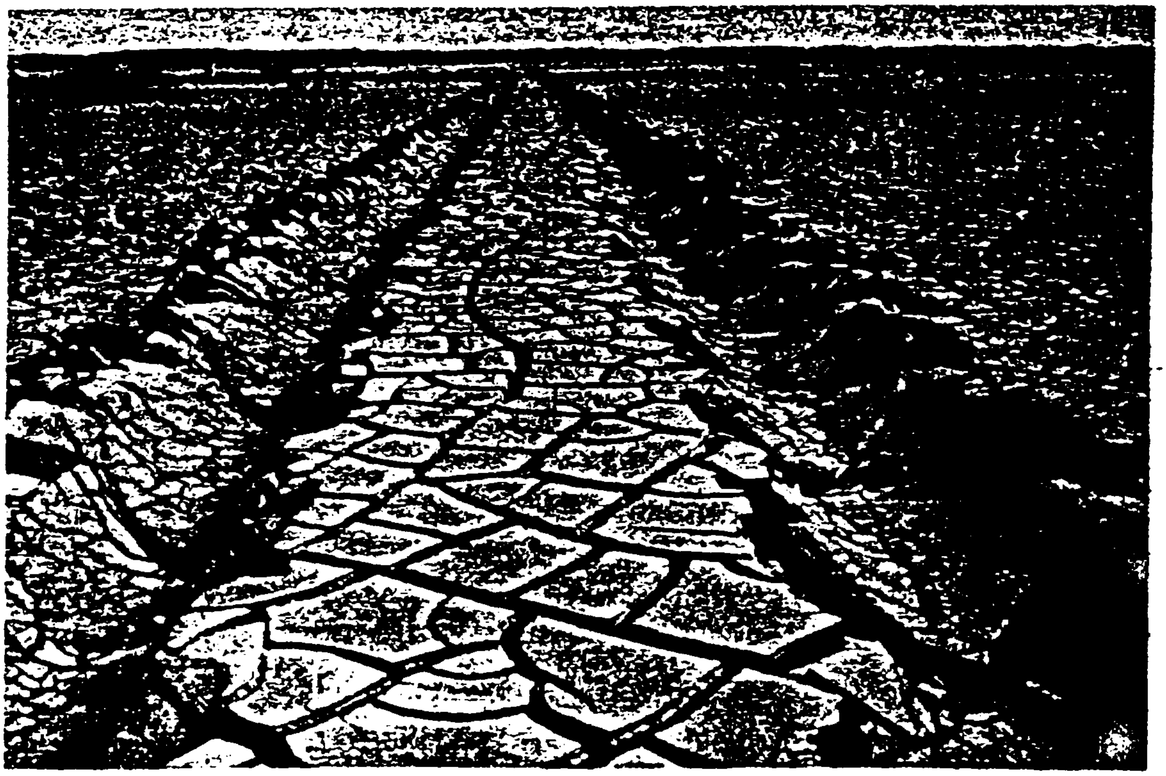


Figure 19. Dredged material surface drying and crust formation produces a crack network draining directly into the RUC drainage trenches

achieved, and the disposal site is ready for final phase active trenching operations, without need for the intermediate phase operations (described subsequently) which must follow perimeter dragline trench construction. Use of the RUC in interior site trenching will also markedly reduce the time until final active phase trenching operations may be initiated.

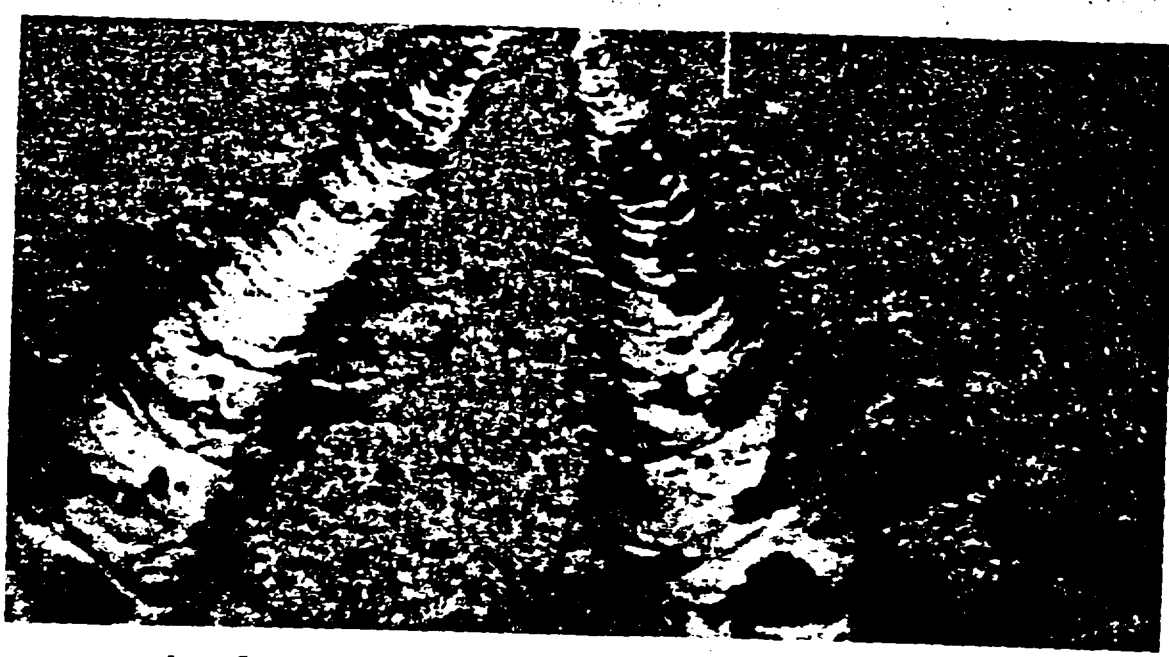
RUC trenching in
existing dredged material

81. RUC trench dewatering concepts are also applicable at sites where disposal has been conducted several months or years previously and, during the interim, a desiccation crust has formed over some or all parts of the disposal area. The RUC conducts optimum trenching when it breaks through the surface crust and floats in the semiliquid subcrust. When the existing surface crust thickness is approximately 8 in. or less, the RUC will break through the crust on the first trenching pass. However, as crust thickness approaches 8 to 10 in., the initial RUC pass produces an incomplete trench, as shown in Figure 20a, and a second pass is necessary. However, this crust thickness and consistency allow development of an extremely well-formed trench on the second pass, with a trench flowline some 8 in. below the base of surrounding crust (Figure 20b). When existing surface crust thickness is between 10 and 12 in., three or four passes may be necessary to produce a complete trench, and, once crust thickness exceeds approximately 12 in., the RUC rotors will not penetrate the crust and produce an acceptable trench, even after a large number of repetitive passes. Thus, 12 in. represents the approximate limit of crust thickness the RUC can trench satisfactorily. However, it should be noted that, if a 12- to 15-in. crust exists at the disposal site, final phase operations can usually be initiated and there will be no need for RUC trenching.

Location and spacing of RUC trenches

82. The expected mechanism for removing precipitation runoff when dewatering by improved surface drainage is by drainage through desiccation cracks to drainage trenches and hence off the site. Thus, one method of proper RUC trenching would be to construct only the minimum

a. Incomplete RUC trench produced on initial trenching pass



b. Completed and well-formed RUC drainage trench produced on second trenching pass

Figure 20. A two-pass trenching technique is necessary to construct proper drainage trenches when surface crust thickness approaches 8 to 10 in.

number of trenches necessary to prevent precipitation ponding on the disposal area surface and extend directly to low spots containing ponded water. However, the greater the number of RUC trenches per unit of disposal site area, the shorter the distance through desiccation cracks precipitation runoff will have to drain before encountering a drainage trench. Thus, closely spaced RUC trenches should produce more rapid precipitation runoff and may slightly increase the rate of evaporative dewatering. Conversely, the greater (in direct proportion) the number of RUC trenches constructed per unit of disposal site area, the longer the RUC must operate and the greater the cost of dewatering operations. However, the RUC has a relatively high operational speed, and it is therefore recommended that the maximum number of drainage trenches be placed by the RUC consistent with the specific trenching plan selected. If topographic data are available for the disposal site interior, they may be used as the basis for preliminary planning of the trenching plan. The RUC can deepen any existing drainage channels and cut through ridges and mounds which currently inhibit drainage.

83. Radial or finger trenching. An inherent disadvantage of a trenching plan involving rectangular grids of RUC trenches is that the vehicle tends to seal previously made trenches when crossing its own tracks and handwork is necessary to reopen the trench intersections. The optimum procedure for constructing RUC trenches makes use of a radial or finger technique to avoid this problem and is as follows:

a. To avoid creating undesired ruts in the fine-grained material, the RUC enters the disposal area near the dredge pipe location, where a mound of cohesionless material is usually deposited. If no mound of cohesionless material exists in the disposal area, the RUC may enter at any point, staying close to the perimeter dike. The vehicle then makes a perimeter trench parallel with and adjacent to the dike, from its entrance point to the first-encountered outflow weir.

b. The RUC then constructs a shallow depression or sump in front of the outflow weir by pivoting several times in place to wallow a depression. Alternatively, these sumps may have been constructed previously by dragline equipment working from the perimeter dike. A shallow semicircular sump approximately 30 to 40 ft across is most desirable.

c. Once the sump has been constructed, the RUC leaves the sump and enters the disposal area, making a radial finger into the site interior. The finger is constructed until it reaches the outer limit of the disposal area surface which might rationally be expected to provide drainage to the given weir. At this point, the RUC pivots in place and returns down the trench, following its own tracks to reenter the sump. The vehicle again pivots in the sump and reenters the disposal area making another finger adjacent to, but some degrees offset from, the initial finger. Radial spacing of the fingers is normally based on site topographic characteristics and amount of disposal area draining to a particular weir. Empirical field modification of the preliminary trenching plan is very easy to carry out, if warranted. Minimum finger spacing is controlled by the requirement that each set of fingers radiate independently from the weir sump, such that the RUC does not cross its own tracks when making the trenches.

d. Once a set of finger or radial trenches has been completed at one weir location, the RUC leaves the initial sump and makes a perimeter trench along the dike to the next weir location, where the finger trenching procedure is again repeated. The operation is continued until the entire disposal site has been trenched and the vehicle returns to the other side of the sand mound near the dredge pipe location, where it leaves the site. This radial trenching procedure, when applied at the 100-acre Drum Island Disposal Site of the Charleston District, required approximately 2.5 hours of continuous RUC operation from site entrance to site exit.

84. When the disposal area is of extremely large extent or when interior cross dikes or other obstructions exist within the disposal area, sequential sets of radial trenches may be constructed, with the sets farthest into the disposal area interior acting as collectors funneling into one of the radial trenches extending from the outflow weir. This sequential radial trenching procedure is shown in Figure 21, as constructed in the South Blakeley Island Disposal Site of the Mobile District.

85. Parallel trenching. An alternate scheme of making RUC drainage trenches is for the RUC to make a complete circuit of the disposal area perimeter and then construct parallel trenches back and forth across the disposal area, ending in the perimeter trench. Spacing between parallel trenches can be varied as desired. This procedure was

Figure 21. Aerial view of sequential radial trenching procedure used when interior cross dikes are encountered; South Blakeley Island Disposal Site of the Mobile District

originally developed by the Dutch, who use the Amphirol, a small twin archimedean screw vehicle approximately one third the RUC's size, to make initial drainage trenches during their polder reclamation operations.[14] WES was not able to obtain an Amphirol for trenching evaluation, but studies were conducted with the Marsh Screw Amphibian shown in Figure 22, a prototype military vehicle approximately the same size and horsepower as the Amphirol. The Marsh Screw was found to be satisfactory for use in disposal area survey and reconnaissance activities but was not found suitable for extended disposal area dewatering. In the Dutch procedure, the Amphirol makes trenches on about 8 ft center-to-center spacings across the entire disposal area, though, if the crust is greater than about 2 in., shallow depressions are produced in the surface rather than a complete drainage trench cut through the crust, as constructed by the RUC.

86. Numerous problems will exist whenever RUC trenches across the disposal area intersect the perimeter RUC trench, as the vehicle will

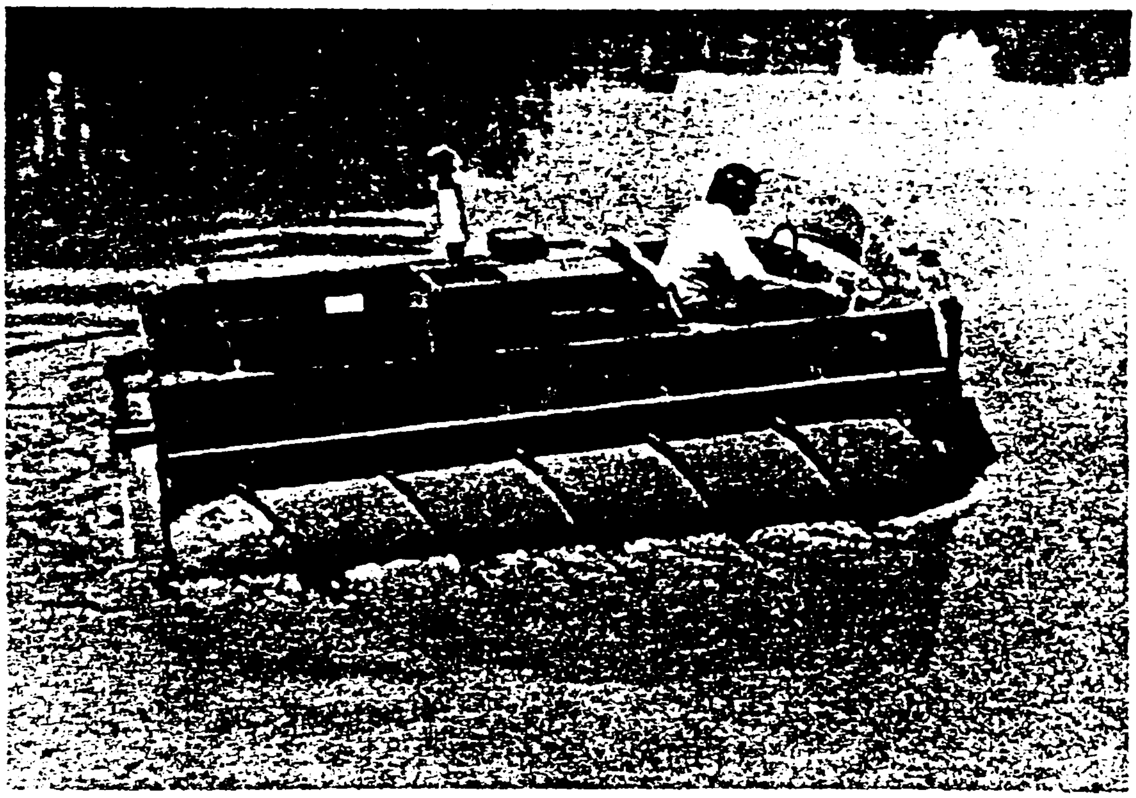


Figure 22. The Marsh Screw, a smaller archimedean screw amphibious craft

tend to seal off one set of tracks. The Dutch also encountered this problem, and handwork was necessary to complete the Amphirol trench network.[14] Because of the large amount of handwork necessary, this procedure is not recommended as an alternative to radial or finger trenching unless either:

a. Because of site configuration or other conditions, the radial trenching plan does not appear operationally viable.

b. The perimeter trench may be constructed by dragline, such that a wide shallow trench is produced, allowing the RUC to enter the trench when completing one pass, move down the trench, climb the bank, and reenter the disposal area without crossing a set of its own tracks in such manner as to inhibit drainage. In such combination RUC-dragline trenching, the closest practical trench spacing is probably on the order of about 9 ft, the center-to-center spacing of RUC rotors.

87. Combination finger-parallel trenching. When relatively long, narrow disposal areas are encountered, with the dredge pipe located at one end and outlet weirs at the other, a combination radial-parallel RUC trenching procedure may give best interior drainage. Such a completed trenching network is shown in Figure 23. Radial trenches are made from each weir sump into the disposal area, then the RUC turns and makes trenches parallel with the long perimeter dikes, pivoting and returning down each trench to the weir before making another.

88. Limitations in RUC trenching. Besides the operational limits of 12-in. untrenched crust thickness and 18-in. maximum trenching depth mentioned previously, two other factors may inhibit or limit RUC trenching effectiveness:

a. Inability to grade or control trench flowline elevation.

b. Trenching difficulty in sand.

As the depth of RUC-constructed trenches is controlled by crust thickness and material consistency, a uniform trench depth is normally produced in areas where fine-grained material is deposited. Trench flowlines thus tend to follow the natural contours of the filled disposal area, which usually grades gradually from dredge pipe location to outlet weirs. Because most effective trenching is conducted when the RUC floats in the subcrust, it is difficult to establish a continuous grade

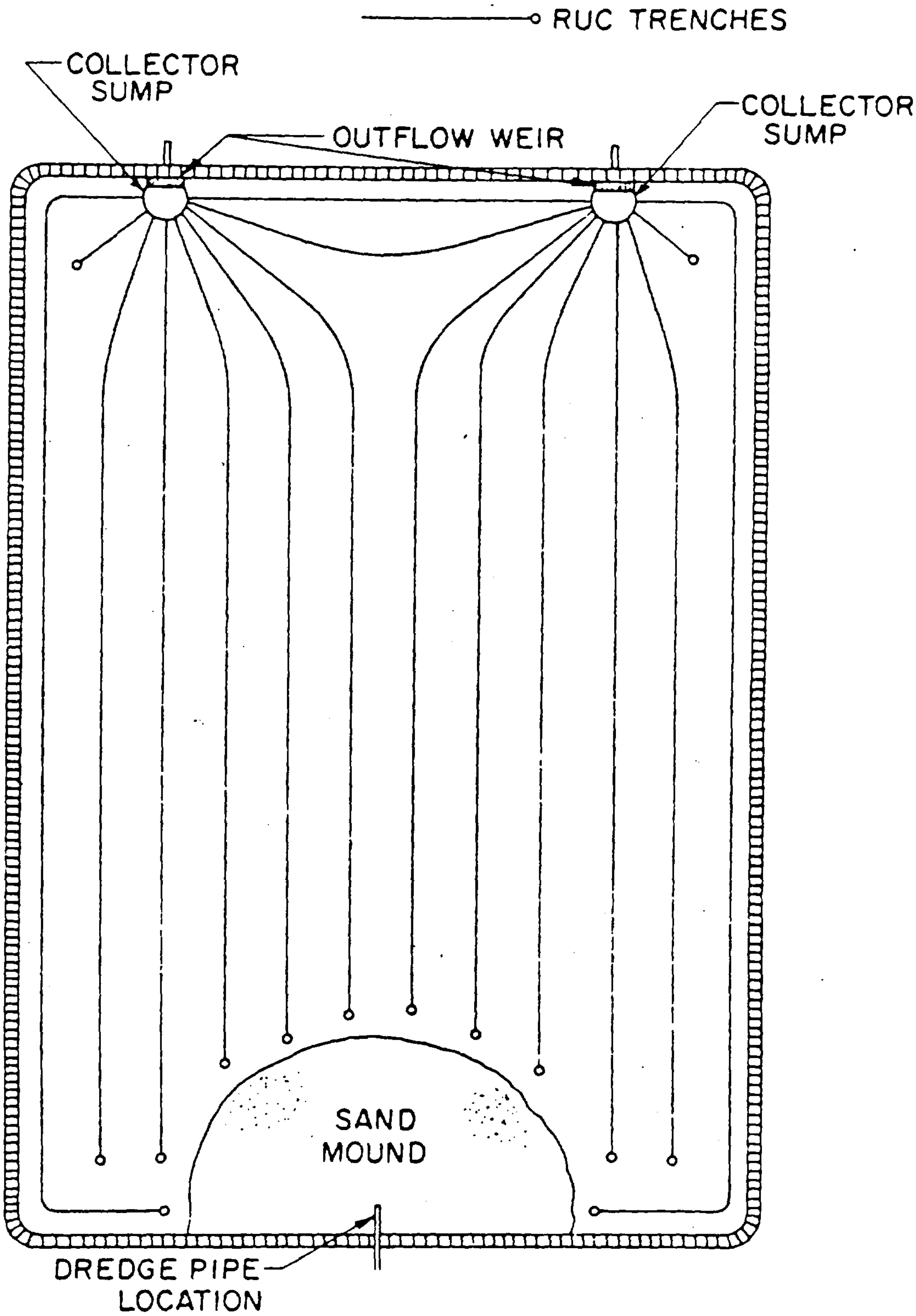


Figure 23. Combination radial-parallel trenching scheme

when harder subcrust layers exist (sand layers, old interior dikes, etc.). Making repeated passes is not always effective as the "floating" RUC simply rides up and over hard spots. The most effective procedure found during DMRP field trials was to stop and reverse through the hard spot. Engine torque forces the rear of the vehicle down and the blunt rear end of the rotors will tend to gouge out the hard material. Going forward again smoothes the trenches. This procedure is often successful only for short periods, as the hard spot will not subside at the same rate as surrounding fine-grained dredged material, and, after a week or two of effective drainage, the trench flowline in the hard area will again be higher than the rest of the RUC trench.

89. When the RUC attempts to traverse or trench sand, excessive friction occurs between the large rotor surface area and the cohesionless material, and a large amount of engine torque is necessary to cause RUC movement. Continued trenching in sand may cause transmission overheating or drive unit bearing failure. The best mode of traversing sand is by lateral movement, rotating both rotors in the same direction. Dike climbing and other activities involving forward RUC movement in sand should be conducted at very slow (1- to 2-mph) speeds to minimize stresses on RUC drivetrain components.

90. The RUC rotors are constructed of relatively thin (0.125-in.) aluminum alloy. Thus, they are susceptible to denting and puncture from logs, bricks, stumps, and other debris found in disposal areas, nearshore, and in open water. While the styrofoam-filled rotors provide mobility even if punctured, normal care should be taken when operating the vehicle to prevent unnecessary and expensive rotor replacement.

Improvement of Disposal Area Surface Drainage--Intermediate Active Phase

91. Periodic dragline perimeter trenching may develop a 12- to 18-in.-thick surface crust adjacent to the perimeter trenches within approximately 9 to 12 months after operations are initiated. The crust will decrease in thickness toward the disposal site interior, with actual thickness at the site interior dependent upon disposal site size

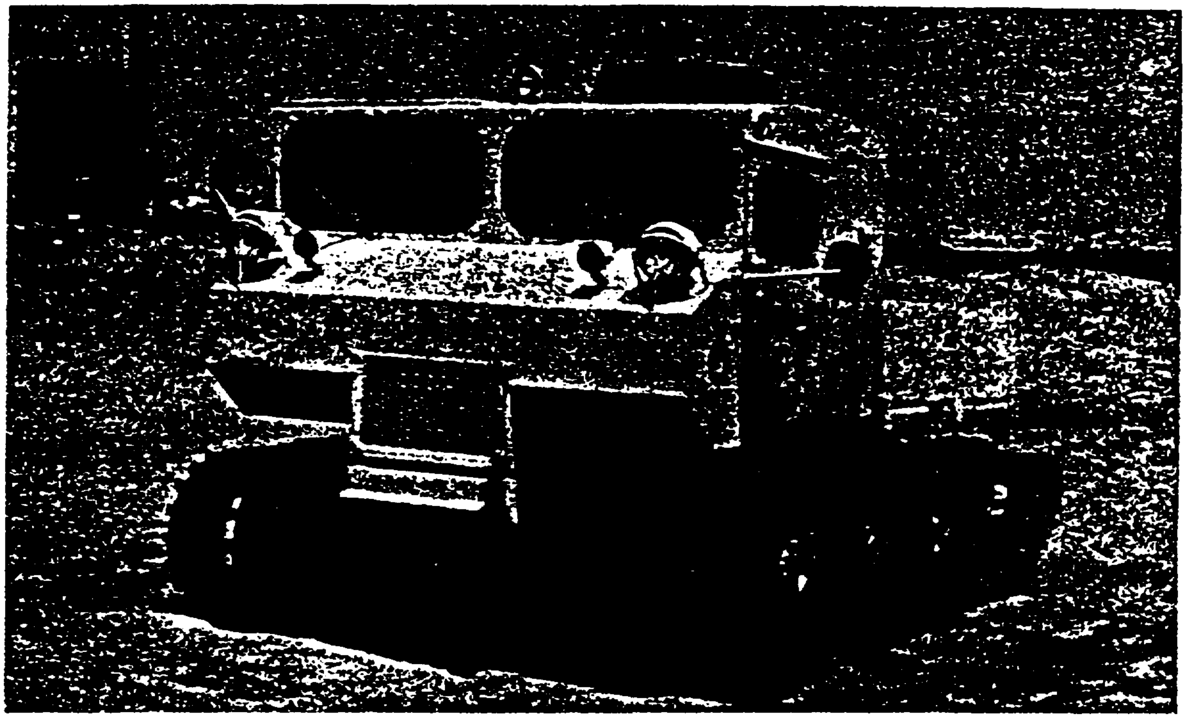
and whether or not any low spots exist which retain ponded surface water. However, once some perimeter crust is established, specialized low-ground-pressure vehicles may work farther into the disposal area, constructing interior drainage trenches from the perimeter inward to the limit of their mobility. These operations will increase the rate of crust formation and dewatering in the disposal area interior.

92. If a RUC is not available to conduct interior trenching operations, three alternative methods were found technically feasible for extending trenches into the disposal site interior after crust formation: a low-ground-pressure tracked vehicle with drag plow, an amphibious dragline, and a small dredge. Procedures for use of these three equipment items will be described in the following sections.

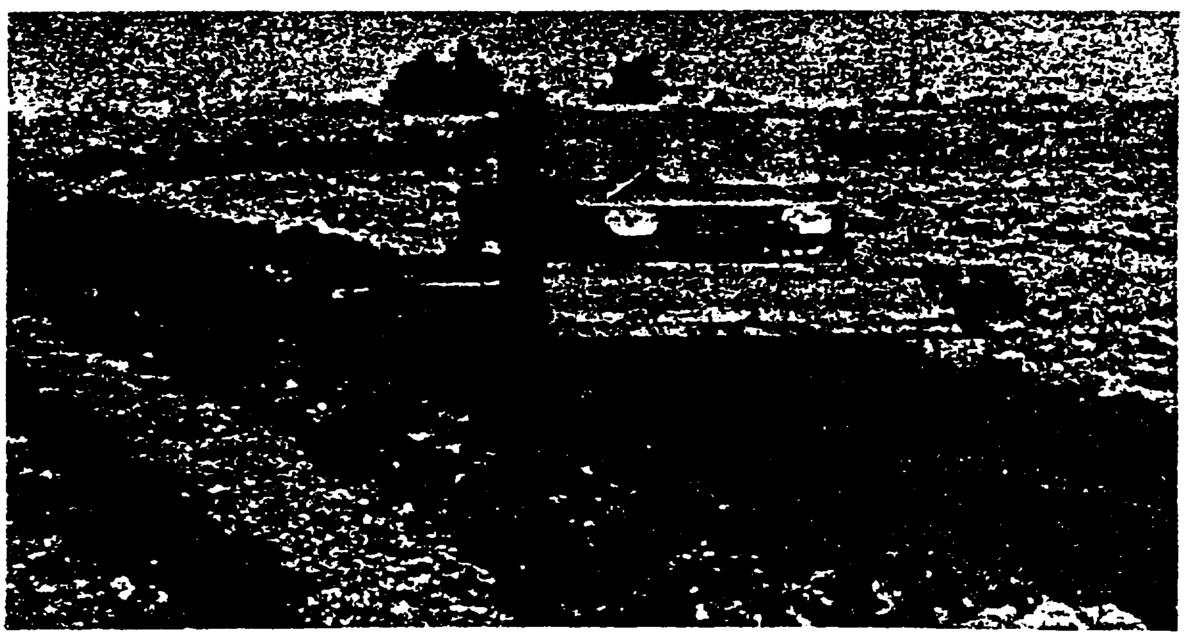
Trenching with a low-ground-pressure tracked vehicle and drag plow

93. The term "Thiokol" describes a general class of low-ground-pressure tracked vehicles made by the Thiokol Chemical Corporation, Logan, Utah. Two models evaluated were the Trackmaster shown in Figure 24a, and the wider-tracked Spryte shown in Figure 24b. The Thiokol vehicles are typical of a number of different low-ground-pressure tracked vehicles commercially available and are mentioned by name only because they were specifically evaluated.[11] Depending upon specific vehicle size and track width, vehicle ground pressure for the various brands of equipment usually ranges from approximately 0.5 psi up to 1.0 psi. The Trackmaster in Figure 24a evaluated by WES is capable of operation with a minimum critical layer RCI of 10. More details concerning commercially available low-ground-pressure vehicles are available elsewhere.[11-13]

94. Method of trenching. On desiccation crust, the evaluated Thiokol Trackmaster had a drawbar pull of approximately 4000 lb and can pull the plow shown in Figure 25 if sufficient critical layer RCI is available.[12] This plow was constructed by WES using a plow chassis produced by the Thiokol Chemical Corporation and available as a standard accessory. Modifications included replacement of the Thiokol-supplied square plow point by the vee point shown in the figure and extension of

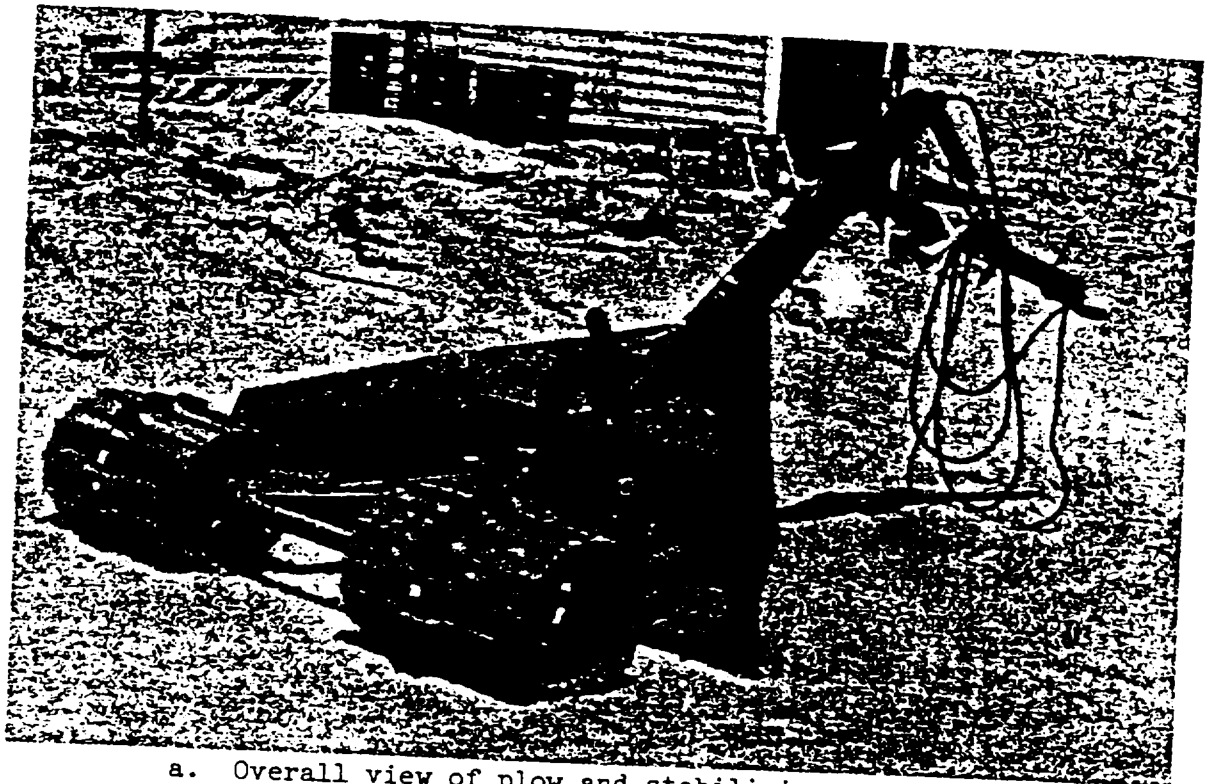


a. Thiokol Trackmaster with ground pressure of approximately 1.0 psi



b. Wider-tracked Thiokol Spryte with ground pressure of approximately 0.6 psi

Figure 24. Thiokol tracked low-ground-pressure vehicles



a. Overall view of plow and stabilizing outriggers

b. View of plow point and moldboard

Figure 25. Drag plow used in Thiokol trenching operations

the moldboard wings. The angle and depth of plow penetration are adjusted by hydraulic cylinders. The plow, when towed behind a Trackmaster or similar vehicle, can make a vee-shaped ditch extending just below the base of existing desiccation crust. The plow is positioned with the point of the vee at the base of the crust. As the plow advances, crust blocks are pulled outward and roll off the moldboard, and minimal effort is expended in attempting to force the plow through underlying semi-liquid dredged material. The plowing operation is shown in Figure 26. Plowing speed for such a vehicle is on the order of 4 to 6 mph, and rental rate for the vehicle and plow is on the order of $35 to $45 per hour.

95. Disposal area trenching procedure. The most effective method of plow trenching is to have the pulling vehicle cross the perimeter dragline ditch and, working on the thick crust adjacent to the ditch, maneuver the plow backwards into the perimeter ditch. The low-ground-pressure vehicle then drags the plow forward constructing a vee trench 1 or 2 in. deeper than existing crust thickness out into the disposal area and which exits into the dragline-constructed perimeter trench. The vehicle can construct this trench (Figure 27) into the disposal area interior until its mobility limit is approached. At such time, the plow is raised and the vehicle returns to make another trench into the disposal area. A set of such trenches extending into the disposal site interior from the perimeter trench will result in increased rate of precipitation runoff from the center of the disposal area.

96. After approximately 4 to 6 weeks, depending upon climatic conditions and dredged material consistency, the trenches may be replowed and/or extended farther into the site interior, as drying during this period should have extended the limit of low-ground-pressure vehicle mobility. After two or three repeated trenchings, it should be possible for the vehicle to plow entirely across the disposal site, producing a continuous trench with outlets into the perimeter trench on both sides of the site. Once the vehicle is able to construct interior trenches successfully across the site, improved drainage and resulting evaporative dewatering should rapidly produce crust on the order of 12 to 15 in.

Figure 26. Trackmaster and drag plow trenching operation in progress

Figure 27. Thiokol drag plow produced trenches extending from the dragline perimeter trench into the disposal site

thick. This crust thickness is normally adequate to support matted draglines in subsequent trenching operations.

97. Operating safeguards necessary while trenching. Low-ground-pressure tracked vehicles are not amphibious and will not float if they break through the surface desiccation crust. For this reason, it is strongly recommended that, prior to conducting such plow trenching operations, the approximate operational limit of the vehicle into the disposal area be determined by measurement of the RCI, which should progressively decrease from a maximum at the edge of the dragline-dug perimeter trench to a minimum in the disposal site interior, using procedures described elsewhere.[12] The minimum vehicle RCI may be determined by use of the mobility chart in Figure 7, entering the chart with the ground pressure of the particular low-ground-pressure vehicle to be used. The multiple-pass curve should be used. Once the critical layer RCI is established and measurements made in the disposal area to determine the RCI profile with distance away from the dragline perimeter trench, locations where the RCI drops below the minimum value should be flagged or otherwise marked. Care should be taken to restrict depth of plowing to only 1 or 2 in. below existing desiccation crust. If the plow is set too deep, excessive drag will force the rear of the pulling vehicle through the crust, immobilizing the vehicle.

98. When plowing or otherwise operating in the disposal area, the vehicle should not attempt to traverse ground previously disturbed by its passage. Should the vehicle encounter mobility difficulties while plowing, the plow should immediately be raised to reduce drag. Should the vehicle still not have sufficient mobility, the plow should be disconnected, and attempts should be made to drive the vehicle onto more nearly stable crust, with the plow retrieved later by winch and cable. In any event, it will be advisable to have the pulling vehicle equipped with a heavy-duty winch and sufficient cable to allow it to retrieve itself or the plow from difficulty. Alternatively, other winch-carrying equipment may be provided with sufficient cable and power to retrieve the vehicle and/or plow from the disposal area.

Disposal site interior
trenching with small dredge

99. An alternative to drag plow trenching is to produce interior trenches with a small, easily mobilized dredge. The Mudcat dredge, shown in Figure 28, is typical of this class of equipment. This small dredge consists of a floating frame containing two diesel engine-powered centrifugal trash pumps. The dredge floats in approximately 2 ft of water and propels itself by winching back and forth along a small, previously set wire cable. Such a dredge may be used to trench the disposal site interior at any time during the dewatering program. However, optimum trenching occurs when there is between 4 and 10 in. of crust. When thinner crust exists, the dredge spends a considerable portion of its digging time removing adjacent subcrust dredged material which flows laterally into the dredge-produced trench. When thicker crust exists, the trenching rate is markedly reduced because the dredge takes about two or three times as long to cut the thicker crust.

100. Method of trenching. The sequence of operations for dredge trenching is to block up outflow weirs and pond water in the disposal area, giving a water depth of at least 2 ft in the dragline-constructed perimeter trench. The small dredge is then brought to the site on a lowboy or other transport and is lifted by dragline or crane and placed in the perimeter trench. If no perimeter trench currently exists, a hole or sump may be dug and filled with water to facilitate dredge entrance.

101. Once the dredge is in the disposal area and begins trenching, it is necessary to keep the dredge floating; thus, pumps to provide water from nearby locations will be necessary. The dredge disposes of crust and underlying material through a trailing pipeline, which may be floated behind the dredge to the bank and then the "re-dredged" material slurry directed onto another portion of the disposal site. If the dredge pipe is properly located, the majority of water will return to the Mudcat trench or dragline perimeter trench, thus minimizing the amount of water which must be added by auxiliary pumps. A Mudcat dredge trenching operation is shown in Figure 29.

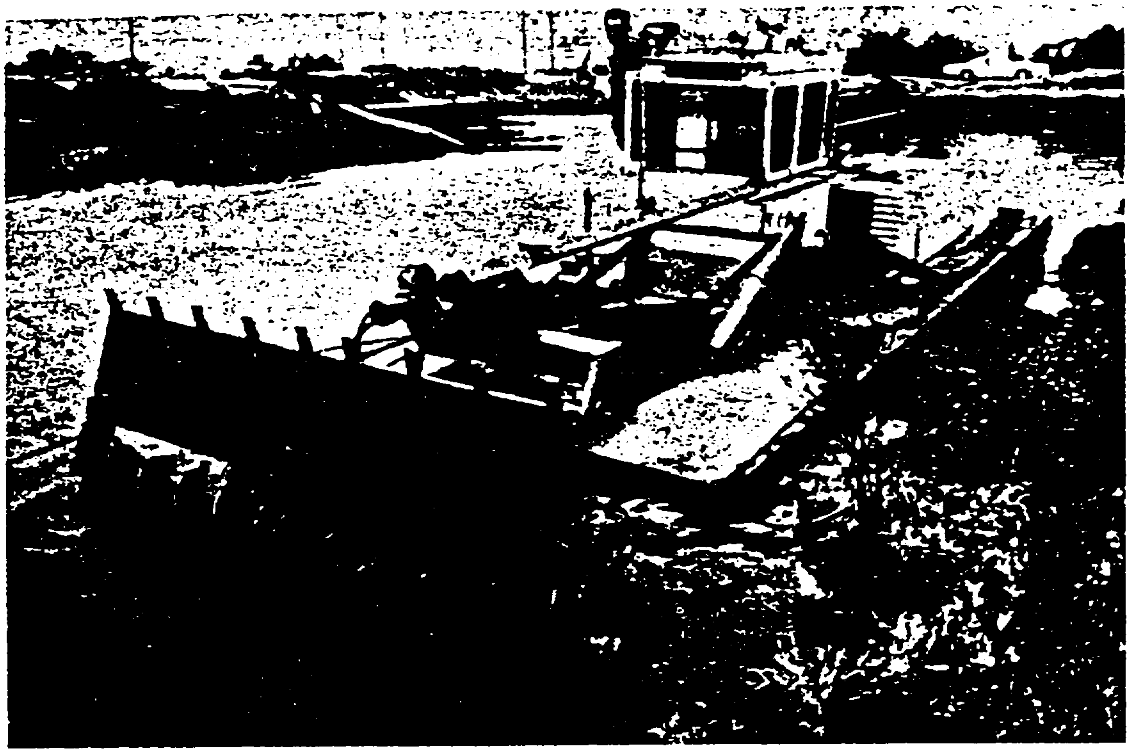


Figure 28. Mudcat dredge used in disposal site interior trenching operations

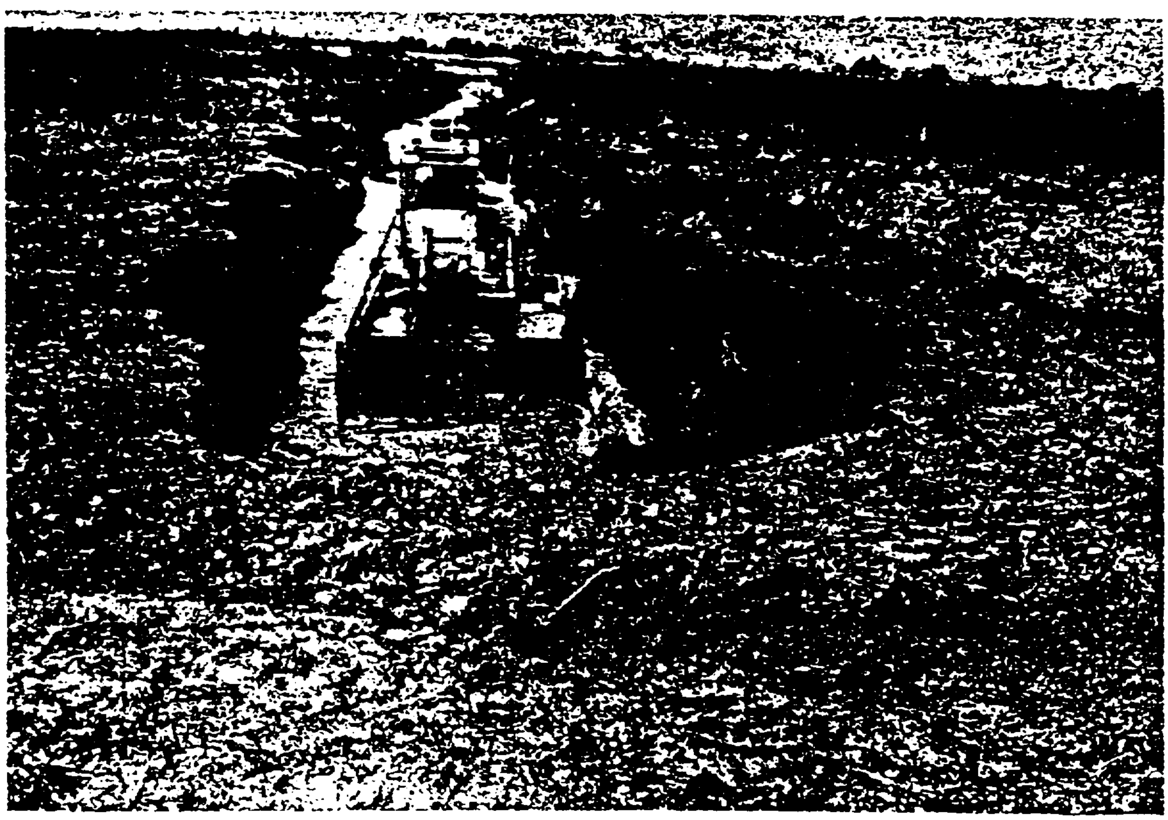


Figure 29. Mudcat dredge trenching operation in progress at disposal site location with approximately 18 in. of surface crust

102. A Mudcat dredge can construct a stable trench approximately 7 ft wide and approximately 6 to 12 in. below the base of adjcaent crust. Attempts to construct deeper trenches will be unsuccessful as the sub-crust dredged material will simply flow back into the created trench within a few hours after trenching has been completed. Rental rate for a Mudcat dredge is on the order of $50 to $75 per hour, and, under optimum conditions, it is capable of producing approximately 200 linear ft of trench per working day. Problems encountered with the Mudcat include its inability to make satisfactory progress in sand and to travel in other than a straight line along its wire cable. In addition, care must be taken when placing the discharge pipe to prevent re-dredged material from washing back into the recently completed trench.

103. Water ponded to facilitate dredge operation improves the stability of the trenches in that immediate bank caving and collapse are retarded. Gradually drawing down the ponded water over approximatly a 1-week period will help to preserve the dredged trenches. A completed interior trench is shown in Figure 30a, while a perimeter trench between outlet weirs originally made by dragline and deepened by dredge is shown in Figure 30b.

104. Summary. Three main advantages exist for use of a Mudcat or similar small dredge as a trenching device:

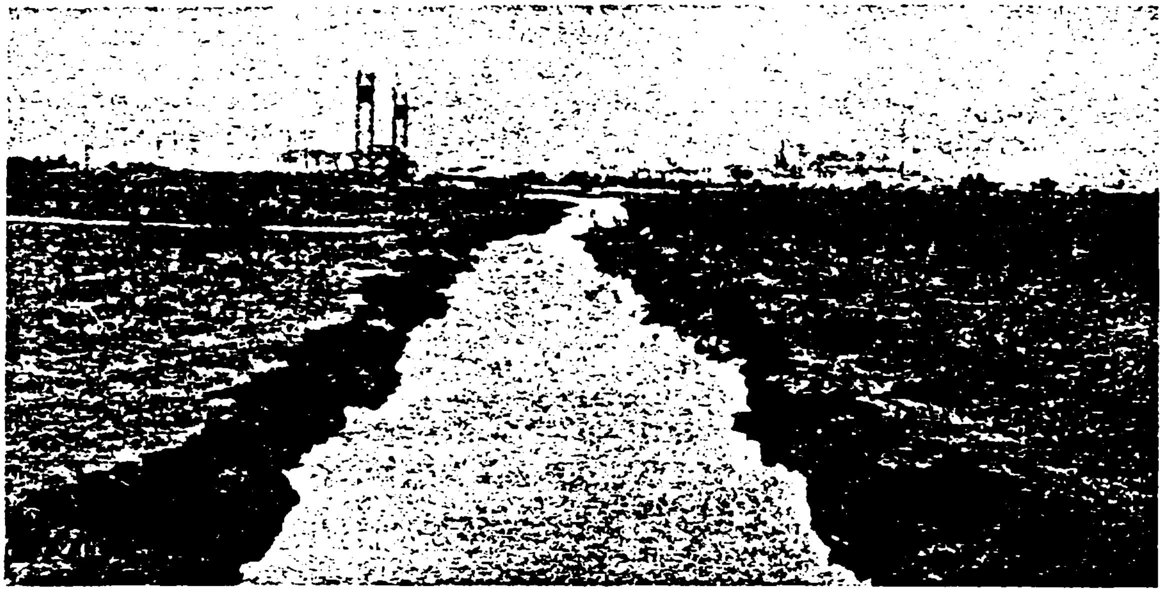
a. The dredge floats in its own trench; thus, immobilization problems which may occur with non-amphibious low-ground-pressure vehicles are eliminated.

b. The relatively wide dredged trench insures that, even if bank caving and collapse occur, the center portion of the trench will likely remain open.

c. Excavated dredged material is disposed as a slurry which tends to spread thinly over adjacent dredged material, allowing it to dry rapidly. Further, large mounds of excavated material are not placed in proximity to trench banks, thus improving trench side slope stability.

105. Conversely, several disadvantages exist relative to use of the Mudcat dredge:

a. As the vehicle is not amphibious, it must be transported to the disposal site, lifted off its transport, and placed in the disposal area.



a. Interior trench constructed in an approximately 10-in. surface crust

b. Deepened perimeter trench between outlet weirs, originally made by dragline

Figure 30. Trenches constructed by Mudcat dredge

b. The dredge requires approximately 2 ft of water for flotation, thus necessitating boarding up outlet weirs and pumping water into the disposal area to float and supply the dredge when trenching.

c. Because of the flotation depth requirement, the dredge must always dig a trench at least 2 ft deep, and 2.5- to 3.0-ft trenches are usually dug during operations. However, the final depth to which the trench may be expected to stand open is only on the order of 0.5 to 1.0 ft below the bottom of adjacent surface crust. In many instances, use of the dredge in thinly crusted disposal areas will result in a considerable amount of wasted excavation, not noticeable in the completed trench network.

Interior trenching
with amphibious dragline

106. Amphibious or marsh draglines, such as that shown in Figure 31, constructed by the Quality Marsh Equipment Company, have been used successfully for excavation in marsh areas and in water. These machines consist of a small- to medium-size dragline placed on a chassis with twin flotation pontoons, covered by a set of wide chain-driven tracks with open growsers. This system enables the machine to swim in open water, and its relatively low ground pressure (1.0 to 2.5 psi) and growser design allow it to track on soft material. However, once the amphibious dragline breaks through the surface crust, the consistency of the subcrust material is usually too viscous for effective swimming and too liquid for effective tracking. Wet dredged material becomes packed in track growsers and the machine becomes immobilized, as shown in Figure 32. Also, amphibious draglines are usually underpowered, capable of only very slow speeds, and low-ground-pressure considerations limit boom length and counterweight size, resulting in a relatively small bucket.

107. The relatively low vehicle ground pressure allows operation in disposal areas with fairly low RCI's (Figure 7). Before attempting amphibious dragline operation on these minimum crust thicknesses, appropriate RCI data required for the particular vehicle ground pressure should be obtained and compared with RCI data for the disposal area. More data concerning amphibious dragline specifications and expected performance are available elsewhere.[1,11,12]

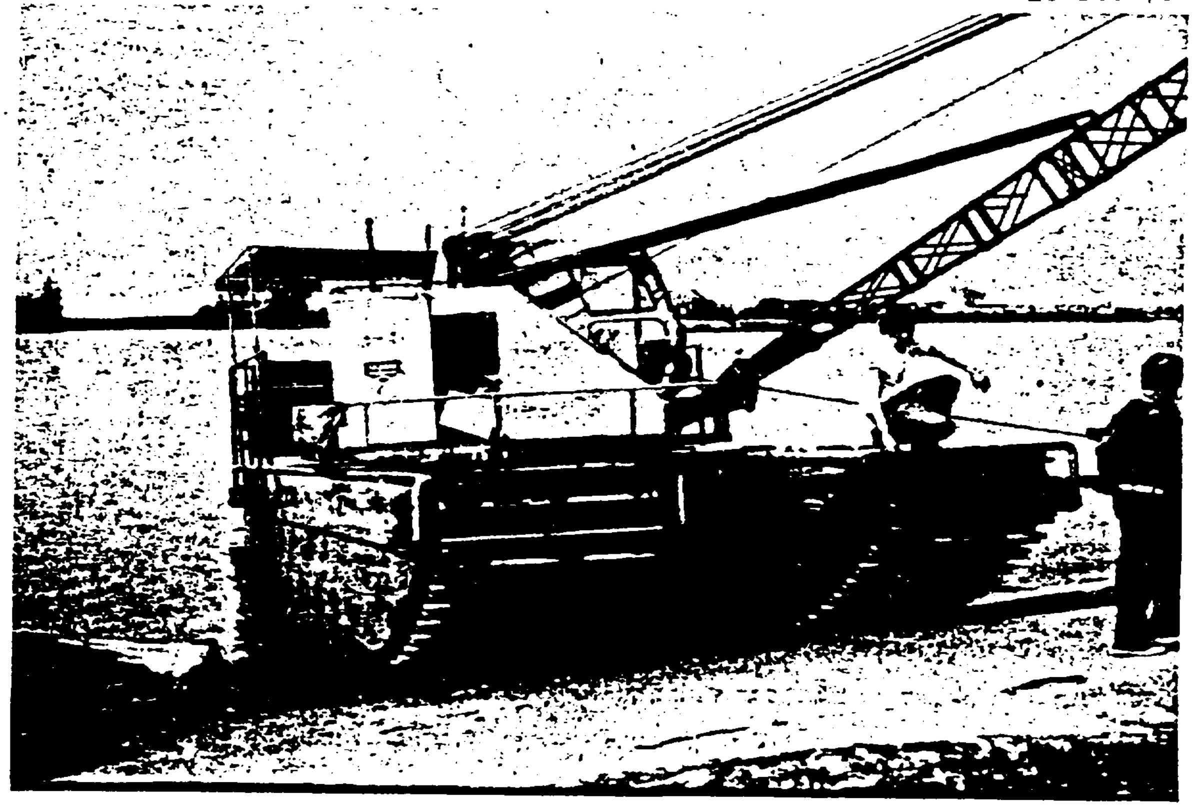


Figure 31. Small amphibious chassis low-ground-pressure dragline manufactured by Quality Marsh Equipment Company

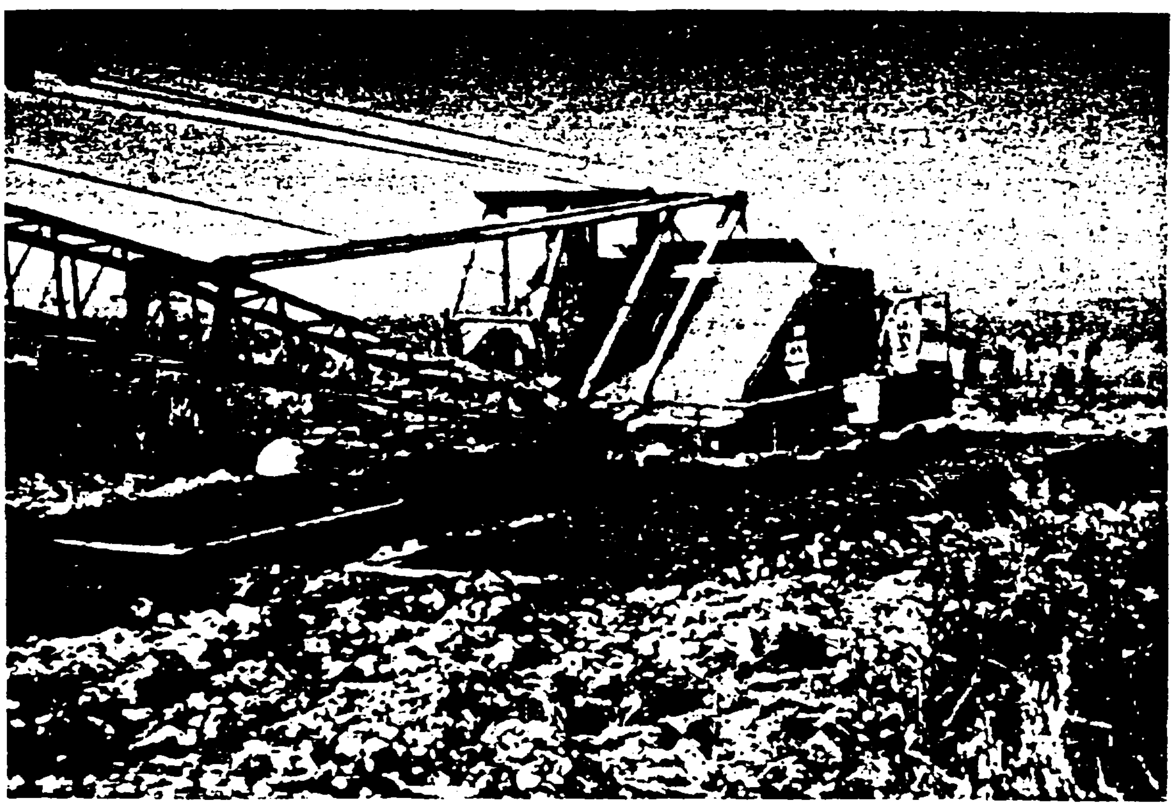


Figure 32. Amphibious low-ground-pressure dragline immobilized after breaking through 4-in. surface desiccation crust

108. If minimum RCI conditions are satisfied, either because the disposal site to be trenched has formed a crust or use of the dragline perimeter trenching technique on freshly placed dredged material has formed a surface crust adjacent to the perimeter dike, amphibious draglines may enter the disposal area and extend the trench network into the site interior. The critical layer RCI is likely to decrease from maximums near the perimeter trench to minimum values in the disposal site interior. As described previously for drag plow trenching, critical layer RCI measurements should be made at intervals into the disposal site prior to vehicle operation, and locations where limiting RCI's prevail should be flagged.

109. Method of trenching. Amphibious draglines may be used to deepen trenches made by the RUC or may be used to trench previously undisturbed crust. The amphibious dragline is capable of constructing trenches with approximately 1V on 1H side slopes, bottom widths of 1.5 to 2.0 ft, and extending approximately 1.0 to 1.5 ft below the bottom of existing desiccation crust.

110. When constructing new trenches, the most efficient procedure appears to be for the vehicle to straddle the proposed center line trailing the boom, digging and casting the excavated material to either side of the trench in broken windrows, as shown in Figure 33, and then flattening the windrows to approximately 1-ft thickness with its bucket. Windrows are broken to facilitate drainage of precipitation runoff into the trench.

111. When deepening previously made RUC trenches, a two-pass technique appears to be the best procedure. On the first pass, the dragline trails the boom sitting on one side of the existing RUC trench and removes the crust from between the two RUC trenches, spreading the excavated material in approximately 1-ft-thick broken, flattened windrows adjacent to the trench. On the second pass, operating from the other side of the trench, the amphibious dragline deepens the entire trench and spreads the excavated material.

112. Expected production rates and related data. Amphibious dragline production will vary with RCI. Anticipated trenching rate may be

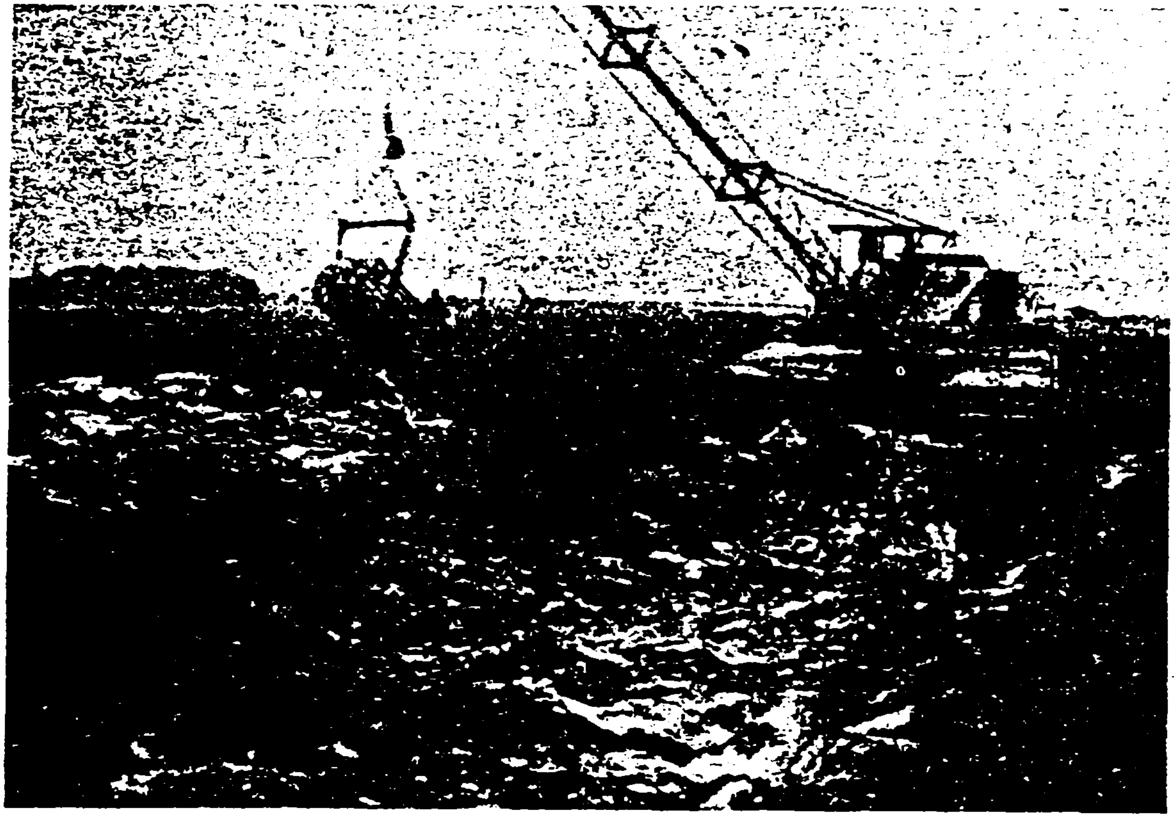


Figure 33. Amphibious dragline constructing initial drainage trenches in 6-in. surface desiccation crust

approximated from the plot in Figure 8, which relates trenching speed in linear feet per hour to critical layer RCI. Data from amphibious dragline evaluations are shown in this figure. A normal amphibious dragline may be expected to have a boom length of 35 to 40 ft and a bucket size of from 3/8 to 5/8 cu yd. Mobilization is usually carried out by barge as the vehicle is too wide for over-the-road transport without track mechanism disassembly. Should an amphibious dragline become immobilized by breaking through surface crust, two alternatives exist for returning it to the surface. The first and most rapid alternative is to pull the vehicle back up onto the crust using a winch and cable located on the perimeter dike. If this is impractical, empty 55-gal oil drums may be chained to the tracks and the machine may, in some instances, be able to walk back up onto the crust under its own power.

113. The amphibious dragline is able to dig wider and deeper

trenches in dredged material than either the RUC or the Thiokol; thus, a longer interval can elapse between periodic trenching intervals. The interior trenching network can be constructed radially from each weir, or a rectangular grid can be constructed over the site. If necessary, excavated crust may be used to fill existing trenches temporarily, for crossing purposes, and then removed. Optimum time for deepening the trenches is when trench depth may be increased by approximately 1.5 to 2.0 ft without need for widening the trench. The time for such deepening may be determined in the field when it is noted that the sides of the trench are relatively hard and contain deep desiccation cracks, such that a man may walk without much difficulty along the bottom of the trench.

114. In subsequent deepenings of amphibious dragline-made trenches, if the crust thickness adjacent to the trenches exceeds 1 ft or a combination of existing crust and dewatered dredged material available as spoil from previous trenching operations may be used to construct a pad above the crust, equally effective results (probably at lower unit operating costs) can be achieved by use of small draglines operating on single or double mats.

Improvement of Disposal Area Surface Drainage--Final Active Phase

115. Once surface crust thickness in the disposal site interior has reached 1 ft or more, it is usually possible for small conventional draglines on mats to traverse the disposal area. Whether single or double mats should be used will depend upon the exact type and weight of the proposed dragline and the critical layer RCI of the dredged material. Detailed field measurements should be made before initiating trenching activities, and, if soil strengths vary, locations where critical layer RCI's are below minimum values should be adequately located and flagged to prevent dragline immobilization.

116. If general rules for assuring sufficient mobility prior to trenching are followed, small-to medium-sized draglines may be used successfully. High variability in dragline equipment is possible

of site access, condition of existing perimeter dikes, time available between disposal cycles, and availability of and probable rental/operating cost for various types of trenching equipment. Some generalizations may be made, however. For example, no vehicle except the RUC is currently available which will conduct effective disposal site interior trenching operations when the critical layer RCI is less than about 10. Also, except for extremely small disposal areas and under special climatic conditions, it is highly unlikely that perimeter dragline trenching alone will produce effective dredged material dewatering in the disposal site interior.

119. The crust thickness may be used as a rough indicator of the strength of the dredged material. Data concerning necessary crust thickness for disposal site interior operation, approximate trenching rate, maximum trenching depth, and estimated unit operating cost are presented in Table 1. Necessary critical layer RCI criteria were given previously in Figure 7 and paragraph 69. Equipment overlap on various crust thicknesses is shown in Figure 34, assuming the critical layer RCI criteria are met. Estimated delay intervals possible between trenching cycles for the various types of equipment and working conditions are given in Table 2. Study of these summary relationships plus the required soil strength mobility criteria in Figure 7 and the production criteria in Figure 8, in conjunction with particular constraints and equipment availability at a given site, should allow determination of appropriate equipment for use, either individually or in sequence, to produce the required trenching. In order to obtain dewatering rates calculated by procedures in the previous section, it is mandatory that a continuing and effective trenching program be developed.

Preliminary Estimation of Trenching Costs

Initial planning

120. Costs of conducting a progressive trenching program will tend to be highly site-specific, depending upon disposal area size, configuration and access, types of trenching equipment available, and whether or

because of variations possible in boom length, counterweight size, bucket size, and track width used with a given basic chassis. As defined herein, a "small" dragline is assumed to carry a 5/8-cu yd or smaller bucket and have an unmatted gross weight of about 40,000 to 60,000 lb, depending upon actual boom, counterweight, bucket, and track configuration. With similar qualification, a "medium" dragline is assumed to carry a 3/4- to 1-cu yd bucket and have an unmatted gross weight of about 55,000 to 75,000 lb. A "large" dragline is assumed to carry a 1-1/4-cu yd or larger bucket and have an unmatted gross weight of 70,000 to 120,000 lb or more. Mats used with all draglines are assumed to be of sufficient size and configuration to reduce ground pressure to acceptable critical layer RCI values (Figure 7). (See paragraph 69 and References 11-13 for more information.)

117. If initially dug with dragline equipment, trenches with 1V on 1H side slopes, 1.5- to 2-ft bottom width, and extending 1.0 to 1.5 ft below the bottom of adjacent desiccation crust may be realized. These trench sizes are similar to those resulting from amphibious dragline trenching operations. If the conventional draglines are used to deepen trenches previously made by the RUC, drag plow, small dredge, or amphibious dragline, slightly deeper depths below existing surface crust may be realized than expected in virgin material, and, in the case of trenches previously made by amphibious dragline, existing trench banks may be left in place. Radial or rectangular trenching plans may be used, as desired. Expected linear trenching capability of the dragline equipment may be predicted from Figure 8.

Summary and Comparison of Trenching Equipment

118. Because several types of equipment have been found effective in progressive trenching to improve disposal area surface drainage, no unique set of trenching equipment and procedures exists. The proper equipment for any dewatering program will depend upon size of the disposal area, whether or not desiccation crust currently exists (and, if so, of what thickness), time available for dewatering operations, type

Table 1

Operational Characteristics of Trenching Equipment

Equipment	Crust Thickness, in., for Effective Operation Minimum	Maximum	Maximum Trench Depth, in.	Approximate Trenching Rate, lin ft/hour	Approximate Rental Cost* $/hour
RUC	0	12	18	2,000+	75-100
Low-ground-pressure tracked vehicle + plow	4	24	24	2,000+	35-45
Small dredge	4	10	30	25	50-75
Amphibious dragline	6	18**	Crust + 18	40	50-70
Small dragline on double mats	12	18†	Crust + 18	30	35-50
Medium dragline on double mats	12	18†	Crust + 18	40	40-50
Small dragline on single mats	18	24††	Crust + 18-24	50‡	35-45
Medium dragline on single mats	18	30††	Crust + 18-24	60‡	40-50
Large dragline on single mats	24	36††	Crust + 24	80‡	45-55

Note: a. Vehicle or mat ground pressure must also satisfy critical layer RCI mobility criteria in Figure 7 and paragraph 69.
b. Low-ground-pressure tracked vehicle assumed to pull drag plow with point set only 1 or 2 in. below existing crust.
c. More exact definitions of dragline equipment given in Paragraph 116 and Reference 13.

* Southeastern U. S., 1977.

** Above this crust thickness, conventional dragline is usually more efficient.

† Above this crust thickness, use single mats.

†† Above this crust thickness, no mats required.

‡ Increase rates 10 lin ft/hour if dragline is working from perimeter dike.

of site access, condition of existing perimeter dikes, time available between disposal cycles, and availability of and probable rental/operating cost for various types of trenching equipment. Some generalizations may be made, however. For example, no vehicle except the RUC is currently available which will conduct effective disposal site interior trenching operations when the critical layer RCI is less than about 10. Also, except for extremely small disposal areas and under special climatic conditions, it is highly unlikely that perimeter dragline trenching alone will produce effective dredged material dewatering in the disposal site interior.

119. The crust thickness may be used as a rough indicator of the strength of the dredged material. Data concerning necessary crust thickness for disposal site interior operation, approximate trenching rate, maximum trenching depth, and estimated unit operating cost are presented in Table 1. Necessary critical layer RCI criteria were given previously in Figure 7 and paragraph 69. Equipment overlap on various crust thicknesses is shown in Figure 34, assuming the critical layer RCI criteria are met. Estimated delay intervals possible between trenching cycles for the various types of equipment and working conditions are given in Table 2. Study of these summary relationships plus the required soil strength mobility criteria in Figure 7 and the production criteria in Figure 8, in conjunction with particular constraints and equipment availability at a given site, should allow determination of appropriate equipment for use, either individually or in sequence, to produce the required trenching. <u>In order to obtain dewatering rates calculated by procedures in the previous section, it is mandatory that a continuing and effective trenching program be developed.</u>

Preliminary Estimation of Trenching Costs

Initial planning

120. Costs of conducting a progressive trenching program will tend to be highly site-specific, depending upon disposal area size, configuration and access, types of trenching equipment available, and whether or

Table 2

Estimated Interval Between Trenching Cycles for Various Equipment Items in Fine-Grained Dredged Material

Equipment Item	Equipment Location in Disposal Area	Initial Condition of Disposal Area Surface	Estimated Trenching Interval
RUC	Interior	Decant point	Each 2 weeks for first month, monthly thereafter
RUC	Interior	Crust $\geq$ 2 in.	Monthly
Low-ground-pressure tracked vehicle + plow	Interior	Crust $\geq$ 4 in.	Monthly
Small dredge	Interior	4 in. < crust < 10 in.	4 months
Amphibious dragline	Interior	Crust $\geq$ 6 in.	4 months
Conventional dragline	Interior	Crust $\geq$ 12 in.	4 months
Conventional dragline	Perimeter	Decant point	Monthly for first 3 months, bimonthly for next 3 months, 4 months thereafter
Conventional dragline	Perimeter	2 in. < crust < 6 in.	Bimonthly for first 4 months, 4 months thereafter
Conventional dragline	Perimeter	Crust $\geq$ 6 in.	4 months

Note: Vehicle or equipment must meet critical layer RCI criteria given in Figure 7.

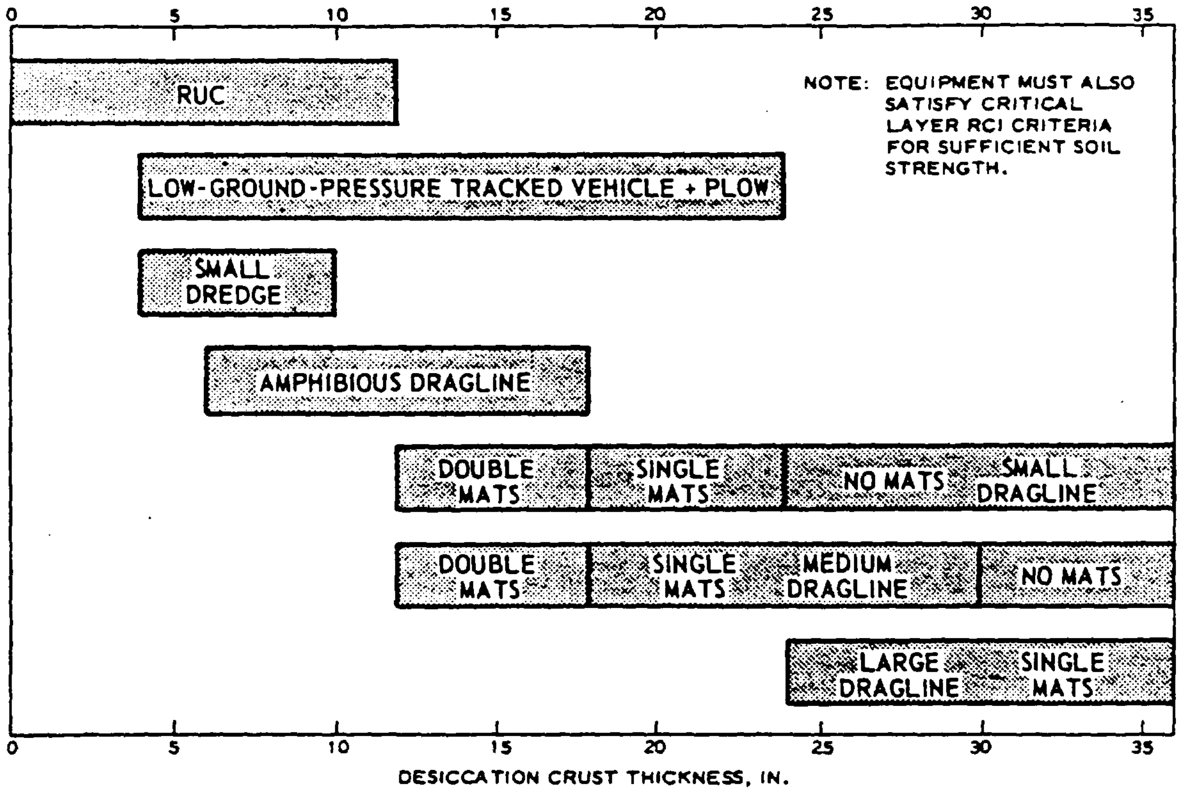


Figure 34. Bar chart showing approximate crust thickness necessary for effective disposal site interior trenching operations by various equipment items

not an aggressive and continuous progressive trenching program is undertaken as part of the overall disposal site management plan. However, for any specific site and best estimate of trenching equipment available, a preliminary trenching plan may be laid out on a plan of the disposal area, and the needed linear trenching distance may be estimated. The frequency of trenching required may be estimated from Table 2 for the equipment selected from Table 1, and the total thickness of crust expected from dewatering estimated from equations given previously. If interior site trenching is conducted initially, an approximately linear crust growth rate with time may be assumed over the entire site. If perimeter trenching only is conducted initially at the site, the expected crust thickness development rate will occur around the disposal area perimeter, but the crust development rate in the disposal area interior may be considerably less. The actual interior crust development rate without interior trenching will depend on climatic conditions, disposal area size, properties of the dredged material, site topography, and whether or not any previous lift of material was completely dewatered. Site operation and management criteria are described in Part IV to maximize effects of trench dewatering.

121. When rate of crust formation estimates have been developed and equipment selected, data given in Tables 1 and 2 concerning approximate crust thickness needed for operation, expected trenching rate, and probable delay interval between periodic trenching cycles for specific equipment items will allow a preliminary trenching program for the site to be developed. The total estimated operating hours for each item of equipment may be determined, an appropriate downtime or nonproductive work factor added (in lieu of better data, an operational efficiency of 70 percent may be assumed for the work, i.e., 30 percent of the work time will be spent in nonproductive activity), equipment mobilization and demobilization estimated, and agency administrative costs determined. Once the total estimated cost is found and compared with expected volume gain data from relationships given in a previous section, an estimated cost per cubic yard of disposal area volume gained may be computed and compared with the value assigned such space; an estimated benefit-cost ratio may then be computed. In general, if dredged material dewatering is to be considered a viable and cost-effective alternative, the dewatering program must be conducted at the most rapid rate predictable under existing conditions. For this reason, whatever the dewatering scheme chosen, its goal should be to obtain a desiccation crust at least 1 ft thick over the entire disposal site as rapidly as possible, to allow site interior trenching operations by conventional dragline equipment. Such equipment is readily available on the market, and trenches constructed by this equipment will remain open without need for retrenching for 4 months or more after construction, minimizing the amount of effort that must be devoted to planning, conduct, contracting, and inspection during the dewatering phase.

122. During actual conduct of the trenching program, estimated data from Tables 1 and 2 may be replaced with results from the actual

operation, allowing a better estimate the next time a preliminary trenching plan must be formulated. Trenching time and cost estimation concepts will be illustrated by example for RUC plus dragline trenching in the following subsection. Other dewatering plans with different equipment may also be formulated, using the illustrated concepts. However, data on expected site interior dewatering rates without interior trenching are not available; thus, a rational example for such work cannot be developed at this time.

Example illustrating cost for RUC plus conventional dragline trenching

123. The 100-acre disposal site example described previously will be used to illustrate application of the above concepts. As shown in Figure 35, the site is assumed to be oval and contain three outflow weirs. Using previously described concepts, a radial RUC trenching layout was developed for the area, shown by the solid lines in the figure. After RUC trenching has developed a thick enough crust to support conventional draglines in the site interior, the draglines are used to deepen the perimeter and every other RUC trench, as shown by the dotted lines in the figure.

124. Trenching--first year. Previous computations for the example indicate that 16 in. of surface crust will be developed by dewatering, or about 1.33 in./month. Initial site trenching is to be conducted by the RUC, and conventional draglines will be used to deepen the RUC trenches when crust thickness reaches 12 in. At a crust growth rate of 1.33 in./month, 9 months of RUC trenching will be required. A total working time of 4 hours, including mobilization/demobilization from the nearby vicinity, is estimated for each RUC trenching. Total RUC trenching required (Table 2) is estimated as each 2 weeks for the first month, then monthly thereafter until a 12-in. crust is produced. Total operating hours and expected crust growth are as follows:

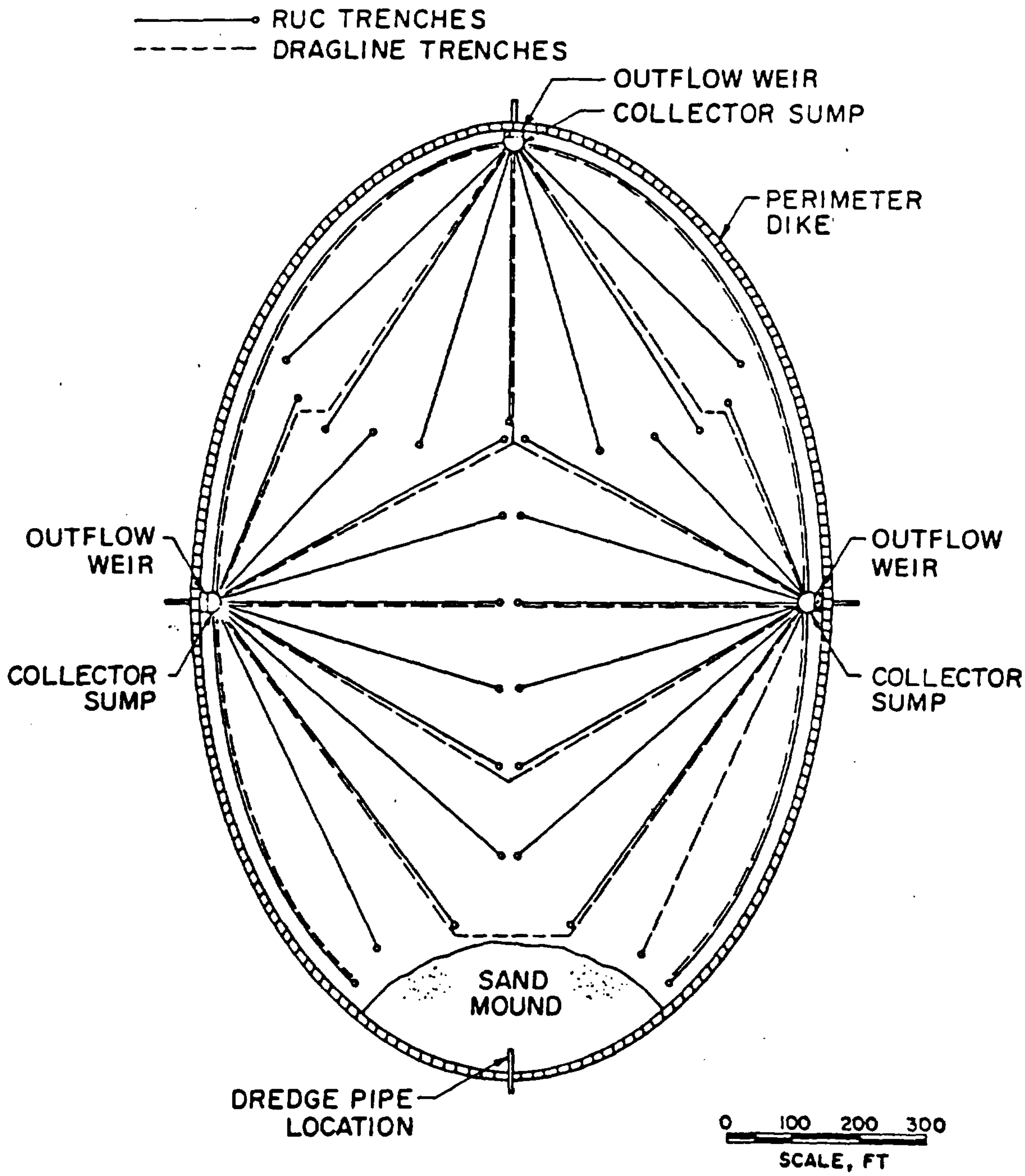


Figure 35. Example of typical surface trenching plan using the RUC and conventional dragline equipment in 100-acre oval disposal area

Elapsed Time months	RUC Time hours	Estimated Crust Thickness at Start of Trenching in.
0	4	0
0.5	4	0.7
1	4	1.3
2	4	2.7
3	4	4.0
4	4	5.3
5	4	6.7
6	4	8.0
7	4	9.3
8	4	10.6
	Total 40	

During the 8th month, another 1.33 in. of crust development will occur. Thus, 40 hours of RUC trenching at $75/hour or $3,000 will be the time and cost estimated to produce the 12 in. of crust necessary for conventional dragline operation, which will be initiated at the beginning of the 9th month.

125. Trenching by small dragline may be divided into two operations. Approximately 3,200 lin ft of perimeter trench may be dug at an estimated rate of 60 lin ft/hour, while 6,300 lin ft of interior trenches may be dug at an estimated rate of 30 lin ft/hour. Assuming a dragline rental cost of $40/hour and $1,000 for mobilization/demobilization, cost of dragline trenching beginning in the 9th month would be 3200 lin ft ÷ 60 lin ft/hour or 53 hours × $40/hour or $2,120 plus 6,300 lin ft ÷ 30 lin ft/hour or 210 hours × $40/hour or $8,400. Adding an additional 4 hours to dig and enlarge each of three collector sumps (12 hours × $40 or $480) plus the $1,000 for mobilization/demobilization, a total of $12,000 is estimated for the first trenching on 12 in. of crust.

126. If two draglines are used, the work may probably be completed in 1 month; thus, the program will be completed by the beginning of the 10th month. With the Table 2 estimated delay interval of 4 months

between dragline trenching cycles, no further work is required in the first year, and estimated first-year trenching costs are \$3,000 + \$12,000 or \$15,000 plus agency administrative costs.

127. Trenching--second year. Continuing the program into the second year, a crust growth of approximately 1.33 in./month may still be achieved if effective drainage is provided. Based on the first year's work, dragline trenching will again be required at the beginning of the 14th month, and a crust thickness of 19 in. should be available. Also, dried material excavated during the first trenching and spread adjacent to the trenches may be used to provide a pad of additional thickness. Assuming a small dragline is again chosen (although a medium-sized unit is also viable), the perimeter trenching rate remains at 60 lin ft/hour but the interior trenching rate rises to 50 lin ft/hour because of increased crust thickness. Cost for the second trenching cycle is thus \$2,120 (perimeter trenching) plus 6,300 lin ft ÷ 50 lin ft/hour or 126 hours × \$40/hour or \$5,040. Assuming \$480 to clean sumps plus \$1,000 mobilization/demobilization gives a total cost of \$8,640 for the second trenching cycle, which is assumed to be completed by the end of the 15th month. The next tragline trenching cycle should be initiated 4 months later, at the start of the 20th month.

128. At the beginning of the 19th month, about 25 in. of interior crust should be developed, sufficient to support a medium dragline at a rental rate of \$45/hour and give an estimated interior trenching rate of 6 lin ft/hour. If the medium-sized dragline is also used to construct the perimeter trenches, an estimated trenching rate of 70 lin ft/hour may be used. Estimated costs for the third dragline trenching cycle are thus 3,200 lin ft ÷ 70 lin ft/hour or 46 hours × \$45/hour or \$2,070 plus 6,300 lin ft ÷ 60 lin ft/hour or 105 hours × \$45/hour or \$4,725. Assuming 4 hours × \$45/hour to clean each of three sumps or \$540, and \$1,000 for mobilization/demobilization, a total cost of \$8,335 is expected for the third trenching cycle. If the work is completed by the beginning of the 20th month, no further trenching is necessary during the 2-year trenching program.

129. Summary. Total operating cost for RUC trenching and three

dragline trenching cycles was computed as \$3,000 + \$12,000 + \$8,640 + \$8,335 or approximately \$32,000. However, these data assume the operations are 100 percent efficient. An operational efficiency of 70 percent may be more reasonable for actual field work; thus, a cost of \$32,000 ÷ 0.7 or \$46,000 should be estimated to cover this contingency. Assuming 20 percent or \$9,200 as the estimated administrative cost, a total cost of \$55,200 may be estimated for the 2-year trenching program. From previous example calculations, a storage volume of 720,000 cu yd was created, at a unit cost of \$0.08/cu yd, during the 2-year interval.

PART III: DEWATERING BY UNDERDRAINAGE

Introduction

130. Underdrainage is a dewatering method which may be used either individually or in conjunction with improved surface drainage. In this procedure, collector pipes are placed in either a naturally occurring or artificially placed pervious layer prior to dredged material disposal. Upon disposal, free water in the dredged material migrates into the pervious underdrainage layer and is removed via the collector pipe system. Previous DMRP research[1B,15] identified four mechanisms for dewatering and densification of fine-grained dredged material using pervious underdrainage layers:

a. Gravity underdrainage. This technique consists of providing free drainage at the base of the dredged material. Downward flow of water from the dredged material into the underdrainage layer takes place by gravity. Stresses for the conditions before and after drainage are shown in Figure 36a for a typical layer of fine-grained dredged material.

b. Vacuum-assisted underdrainage. This technique is similar to technique a, but a partial vacuum is maintained in the underdrainage layer by vacuum pumping. This technique greatly increases typical effective stresses in the dredged material, as shown in Figure 36b.

c. Seepage consolidation. In this technique, water is ponded on the surface of the dredged material and underdrainage is provided at the base of the dredged material. Downward seepage gradients then act as a consolidating force, causing densification, with typical effective stress conditions as shown in Figure 36c.

d. Vacuum-assisted seepage consolidation. This technique combines the effects of seepage consolidation with those of an induced partial vacuum in the underdrainage layer. Typical effective stresses for this condition are shown in Figure 36d.

A confined disposal area with impervious foundation and perimeter dikes functions essentially as a stoppered bathtub, since there is no drainage other than from the surface. To provide a basis for comparison, typical effective stress conditions in fine-grained dredged material

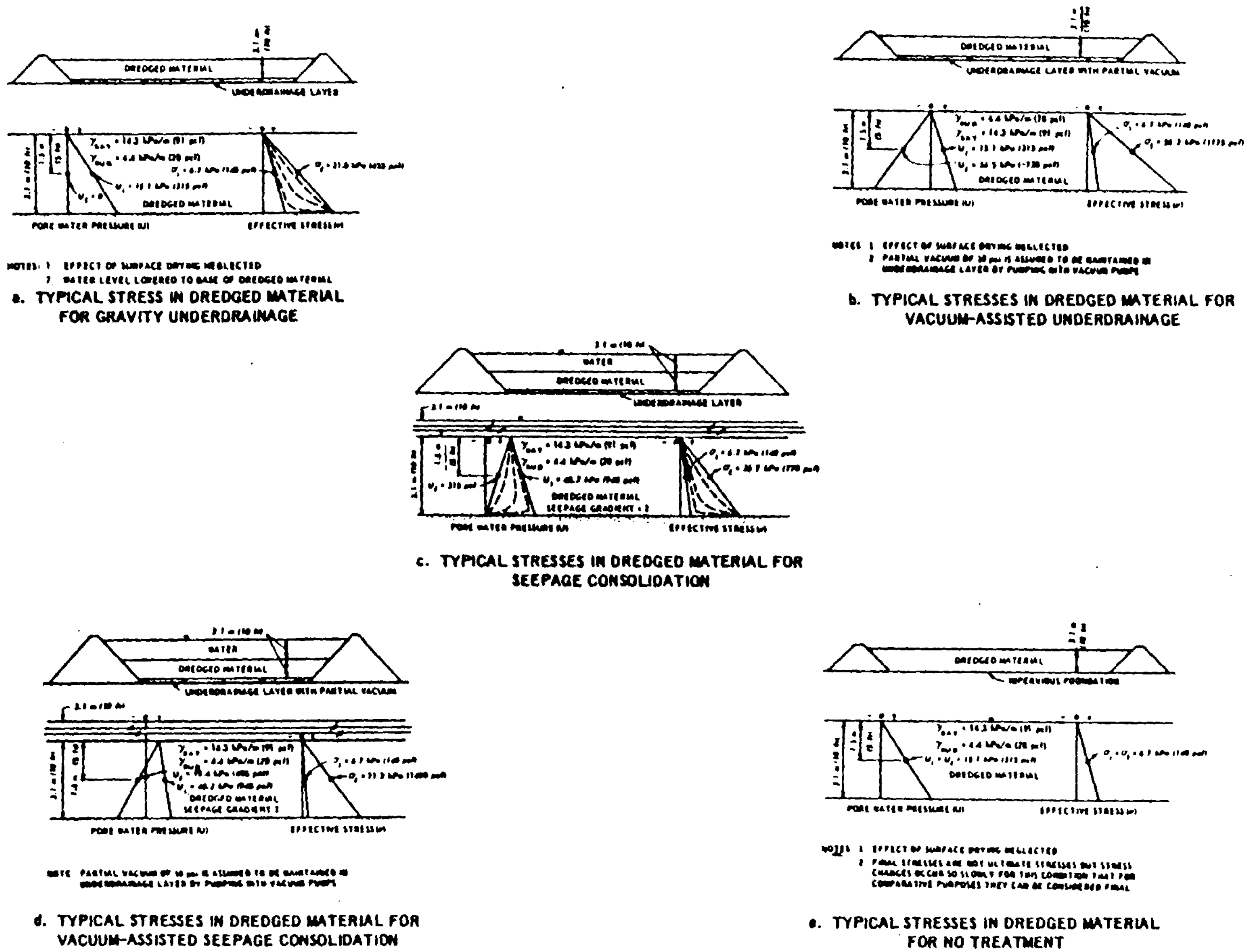


Figure 36. Typical stress conditions in fine-grained dredged material subjected to various forms of underdrainage as well as no treatment

without underdrainage are shown in Figure 36e. Advantages and disadvantages of the various methods are summarized in Table 3.

Conceptual Basis for Underdrainage Dewatering

131. DMRP preliminary research[7] and field experiments[1B,15] confirmed that underdrainage dewatering was a useable concept.

a. Laboratory and field permeability tests[1B,15] indicated that the hydraulic permeability of fine-grained dredged material was about 10^{-4} cm/sec when initially deposited and about 10^{-6} cm/sec after sedimentation and self-weight consolidation. While these permeability values are not overly large, nevertheless they are several orders of magnitude greater than those normally encountered in cohesive soils with much lower water contents.

b. Despite the relatively low hydraulic permeability of fine-grained dredged material, at least a year may be available between disposal cycles, and appreciable seepage might occur over such an interval.

c. Sedimented fine-grained dredged material is extremely compressible and even small changes in the existing stress regime, caused by seepage forces, vacuum-induced negative pore pressures, and/or removal of perched water table conditions, should produce significant consolidation and thus rapidly create additional disposal area volume.

Applicability of Underdrainage Dewatering

132. All underdrainage systems must be installed prior to disposal, and suggested methodology for such installation in both new and existing disposal areas will be described subsequently. Once disposal is initiated, the underdrainage layer will begin to function immediately, assisting to carry off free water which otherwise might be discharged through outflow weirs, as well as producing seepage consolidation and/or accelerating self-weight consolidation in the material deposited immediately over the underdrainage layer. After disposal is terminated, the underdrainage dewatering rate, with resulting surface subsidence and volume creation, appears to be primarily a function of dredged material permeability and whether or not gravity drainage is assisted by

Table 3

Advantages and Disadvantages of Underdrainage Dewatering Methods

Method	Advantages	Disadvantages
Gravity underdrainage	1. Relatively low cost. 2. Sand from required dredging or naturally occurring pervious foundation material may be utilized. 3. Can be used in conjunction with other densification techniques. 4. Filters the dredged material effluent. 5. Can be used in conjunction with surface drying and vegetative growth.	1. Possible construction problems if placement of pervious material is required. 2. Underdrainage layer may occupy storage space in disposal area. 3. Must have collector pipes in order to be effective.
Seepage consolidation	1. Relatively low cost. 2. Almost doubles effective stress in dredged material as compared to underdrainage alone. 3. Allows densification when material is submerged.	1. Requires underdrainage layer. 2. Requires higher dikes to contain water. 3. Prohibits surface drying and vegetative growth. 4. Dike erosion from wave action could be a problem.
Vacuum-assisted underdrainage	1. Cost of adding vacuum pumps to underdrainage system is low. 2. Results in higher effective stress in dredged material. 3. Can be used in conjunction with other densification procedures.	1. Maintenance required during operation. 2. Energy required to operate. 3. Possible problems from leakage which could lessen magnitude of desired vacuum.

maintaining a partial vacuum in the underdrainage layer.[18,15]

133. Advantages of using either gravity or vacuum-assisited underdrainage are that, once initially constructed, the system will operate with either zero maintenance (for gravity underdrainage) or only slight maintenance required to keep vacuum pumps operable (for vacuum-assisted underdrainage) and there will be no need for conducting operations on the surface of the fine-grained dredged material.

134. During initial filling of the area, while a proper ponding depth is being maintained to achieve proper suspended solids concentration in the disposal area effluent, the underdrainage system may act to provide seepage consolidation effects, with downward flow into the underdrainage layer consolidating freshly placed dredged material by seepage gradients. Also, in those instances where it is desirable or necessary to maintain ponded water in the disposal area, as a method of mosquito and/or odor control, to provide improved aesthetics or waterfowl habitat, or for other reasons, placement of an underdrainage layer with provision for removal of collected water will allow seepage consolidation to produce significant dredged material densification.

Requirements for Underdrainage Layer Material

135. Design of an underdrainage layer for use with dredged material is somewhat different than design of a normal pervious filter. A continuous flow condition is usually not maintained in the underdrainage layer. Water essentially drips from the dredged material, and the static water level in the underdrainage layer is at the flowline of the collector pipe system. Fine-grained dredged material placed in confined disposal areas tends to exhibit individualized particle behavior, and it is necessary to choose a filter material that will resist both filter clogging and piping of the fine-grained dredged material through the filter.

136. General criteria for selection of a proper underdrainage material are that it be essentially free-draining and free of fines (5 percent or less passing the U. S. No. 200 sieve) and the material

minimize penetration and piping of the fine-grained dredged material during filter skin formation. Laboratory tests confirmed by field testing[15] showed that either standard well-graded concrete sand or fine uniform sand worked satisfactorily, as did filter fabric with openings equivalent to U. S. No. 70 to No. 100 sieve size placed over any porous and free-draining layer (pea gravel, crushed stone, mussel shell, etc.). Such laboratory testing[15] is recommended prior to selection of an actual site-specific filter design.

137. Sand obtained from new work dredging or as a part of maintenance dredging is usually deposited near the disposal area dredge pipe location and essentially "washed" by the progressive sedimentation process. In many cases, this material will be suitable for use as an underdrainage layer; thus, possible availability and suitability of such material should be one of the initial factors investigated. Comparative data have shown that use of such sand is often extremely cost-effective.[1B]

Prediction Criteria and Illustrative Example of Dewatering Effects

Prediction criteria

138. For preliminary estimation purposes, conservatively assuming underdrainage dewatering begins after dredged material has sedimented, the rate of surface subsidence (and thus volume gain) produced by various types of underdrainage will be assumed essentially independent of stratum thickness. The rate of settlement will be assumed as approximately linear, in direct proportion to the volume of water removed. Efficiency of the dewatering process, assuming a properly designed underdrainage system, is thus a direct function of fine-grained dredged material permeability, and procedures are available[1B,15] for estimation of channel sediment or dredged material permeability. This finding, at first glance, appears to be in contradiction with the theory of dredged material consolidation, which would predict an exponential decay rate of drainage based on layer thickness. However, field studies[1B] indicate

that, if underdrainage layers are present, excess pore pressures* (from self-weight dredged material consolidation) are dissipated in a few months, compared to the multiyear operation length expected for an underdrainage system. Conservatively assuming no contribution from surface evaporative drying, the dredged material surface in the disposal area will subside an amount equal to the volume of water removed. Thus, for preliminary estimation purposes, the rate of settlement caused by gravity underdrainage may be estimated, based on the Darcy equation, as

$$H_s = \frac{Q}{A} = kit \tag{35}$$

where

H_s = dredged material surface settlement, in.

Q = volume of water removed, $in.^3$

A = area through which flow occurs, $in.^2$

k = average permeability of the dredged material, in./year

i = hydraulic gradient of flow, (taken as unity (1.0) if no ponding)

t = time over which flow occurs, years

Procedures for more precise prediction are available elsewhere.[5]

139. The rate of dewatering will be increased if a partial vacuum is maintained in the underdrainage layer. A theoretical development and exact procedure for predicting these effects are available elsewhere.[7] However, for preliminary estimation purposes, field data[1B] have indicated that a negative pressure of -8 psi or less from vacuum application will cause an increase of about 50 percent in the dewatering rate. Also, for preliminary estimation purposes, seepage consolidation may be expected to dewater at roughly the same rate as gravity underdrainage, and application of about -8 psi by vacuum will cause a 30 percent increase in the seepage consolidation dewatering rate.[1B]

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* As used here, excess pore pressures are those pore pressures greater than hydrostatic pore water pressures.

140. The final thickness of underdrainage-dewatered dredged material will depend upon the orignal dredged material thickness and unit weight at the time dewatering is initiated; the consolidation properties, particularly the compression index C_c of the dredged material; the change in average effective stress produced by removal of perched water table conditions through underdrainage; and, if applied, the magnitude of vacuum stresses or downward seepage gradients applied to the dredged material. Precise prediction methods are available for determining the final dredged material thickness and water content, as well as predicting the exact rate of surface subsidence with time, for a given dredged material and underdrainage configuration.[5] For preliminary estimation purposes, surface settlements may be assumed to occur at the previously given rates until the dredged material consolidates to equilibrium under stresses imposed by the underdrainage system. A typical example illustrating such behavior follows.

Illustrative example of
dewatering rate estimation

141. The example 100-acre site filled with 10 ft of fine-grained dredged material at the decant point (1.8 × LL) of Part II will be used for illustrative purposes.

142. In actuality, the underdrainage would begin to function, and accelerate self-weight consolidation, as soon as disposal operations were initiated. However, the dredged material would consolidate to the decant point fairly quickly without underdrainage,[5,6] but consolidation thereafter would proceed more slowly. Comparison with evaporative dewatering also requires both systems to start at the same base water content. The Part II example material had an LL of 100, a specific gravity of solids G_s of 2.7, and a C_c of 0.9. The initial water table level is assumed to be at the dredged material surface and to fall as seepage occurs into the underdrainage layer; thus, a constant downward hydraulic gradient of unity (1.0) is assumed. If the average coefficient of permeability of dredged material is taken to be 10^{-6} cm/sec or 12.4 in./year, use of Equation 35 for a 1-year period would indicate that

$$H_s = (12.4 \text{ in./year})\ (1.0)\ (1 \text{ year}) = 12.4 \text{ in.}$$

or 12.4 in. of vertical surface subsidence may be expected in the first year if gravity underdrainage is used, assuming no surface drying. If the other three underdrainage methods were used, their effects may be estimated as follows:

Underdrainage Dewatering Method	Empirical Multiplier to Gravity Underdrainage Rate	Estimated First Year Surface Settlement in.
Vacuum-assisted underdrainage	1.5	18.6
Seepage consolidation	1.0	12.4
Vacuum-assisted seepage consolidation	1.3	16.1

143. Left to its own devices, fine-grained dredged material will, after an extended period, consolidate from the decant point to a water content near the LL.[7] Availability of underdrainage should allow the material to reach this point much more rapidly (at the previously assumed settlement rates), and cause additional consolidation settlement from removal of buoyant force. The subsidence settlement, in inches, expected $H_{\Delta w}$ as the material goes from its original water content w_{cd} to the LL is

$$H_{\Delta w} = \frac{H_{dm}[0.01(w_{cd} - LL)G_s]}{1 + 0.01w_{cd}G_s} \tag{36}$$

where

H_{dm} = thickness of the dredged material at the time underdrainage dewatering is initiated, in.

w_{cd} = average water content of the dredged material when underdrainage dewatering is initiated, percent

or, for the example where w_{cd} equals 1.8 × LL or 180 percent,

$$H_{\Delta w} = \frac{120[0.01(180 - 100)2.7]}{1 + 0.01(180)2.7} = 44.2 \text{ in.}$$

144. The additional consolidation settlement, in inches, produced by gravity underdrainage removal of buoyant force H_c may be estimated as

$$H_c = \frac{H_{dm} C_c}{1 + 0.01 w_{cd} G_s} \log \frac{p_i + \Delta p}{p_i} \qquad (37)$$

where

p_i = initial effective stress at the center of the original dredged material layer, submerged condition, psf

Δp = change in effective stress produced at the center of the original dredged material layer by perched water table removal, psf

The initial effective stress, in pounds (force) per square foot, at the center of the dredged material layer p_i (psf) may be estimated as

$$p_i = \frac{G_s - 1}{1 + 0.01 w_{cd} G_s} \left(\frac{\gamma_w H_{dm}}{2} \right) \qquad (38)$$

where γ_w = unit weight of salt or fresh water, pcf, or as

$$p_i = \left(\frac{2.7 - 1.0}{1 + 0.01(180)2.7} \right) \frac{64.4(10)}{2} = 93 \text{ psf}$$

while the change in effective stress at this depth from buoyant force removal is

$$\Delta p = \frac{\gamma_w H_{dm}}{2} \qquad (39)$$

or

$$\Delta p = \frac{64.4(10)}{2} = 322 \text{ psf}$$

Substituting into Equation 37,

$$H_c = \frac{10 \text{ ft}(12 \text{ in./ft})0.9}{1 + 0.01(180)2.7} \log \frac{93 + 322}{93} = 12.0 \text{ in.}$$

Thus, if gravity underdrainage was used in the example disposal area, a total of 44 in. plus 12 in. or 56 in. of settlement would be produced by the underdrainage, and, at an annual rate of 12.4 in., the underdrainage system would require 4.5 years of operation for complete dewatering.

145. If a partial vacuum was maintained in the underdrainage layer and was propagated into the dredged material layer, it would cause an additional effective stress of 1,440 psf in Δp. Thus, expected consolidation might be estimated as

$$H_c = \frac{10 \text{ ft}(12 \text{ in./ft})0.9}{1 + 0.018(100)2.7} \log \frac{93 + 322 + 1{,}440}{93} = 24.0 \text{ in.}$$

so that a total of 44 in. plus 24 in. or 68 in. of settlement may be expected. At the estimated vacuum-assisted underdrainage rate of 18.6 in./year, 3.7 years of operation would be required to dewater the material. If the partial vacuum did not propagate through the entire layer during the dewatering interval, effects of vacuum consolidation would be reduced. Similar estimates could be made for the effects of seepage consolidation.

146. Previous work[1B] estimated the costs of installing an underdrainage system (Southeastern U. S., 1977) as $1,600/acre if a pervious foundation was present; $4,970/acre if free sand was available but had to be loaded, transported, and placed; and $6,850/acre if the sand had to be purchased. Annual operating costs of $840/acre were assumed for

maintaining a partial vacuum in the underdrainage layer. Total costs for operating the vacuum-assisted underdrainage system for 3.7 years would be installation cost plus \$840/acre × 3.7 or \$3,110/acre. The volume produced by gravity underdrainage over 4.5 years was 7,530 cu yd/acre, while the vacuum-assisted underdrainage, over 3.7 years, created 9,142 cu yd/acre. Unit volume creation costs for the treatments are summarized as follows:

Treatment	Unit Volume Creation Cost, \$/cu yd: Buy and Place Sand	Place Free Sand	Pervious Foundation
Gravity underdrainage*	0.91	0.66	0.21
Vacuum-assisted underdrainage**	0.90	0.88	0.52

* 4.5 years operation required.
** 3.7 years operation required.

These data illustrate the potential reduction in unit volume creation costs when the proposed disposal site has a pervious foundation, or when sand from previous dredging work can be used.

Summary

147. Once the unit volume creation cost has been determined for the disposal site of interest, administrative costs added, and the total compared with the value assigned such space, appropriate benefit-cost ratios may be determined. It should again be noted that prediction relationships presented previously are very crude and should be used only for preliminary feasibility determination purposes. More precise prediction methods are available for use in actual design,[5] and predicted costs and rates should be replaced by actual site-specific data obtained during system installation and operation, to improve future predictions.

Effect of Combination Underdrainage and Surface Drainage Improvement

148. If a surface drainage improvement program is carried out in conjunction with underdrainage dewatering, the net effect will be to dry the dredged material from both top and bottom simultaneously. The

rate amd the amount of surface subsidence created by this combination procedure may be predicted.[5] For preliminary estimation purposes, it should be assumed that use of both techniques will not create more total new disposal volume than either would separately; however, the total volume will be created at about twice the average of the two predicted dewatering rates.

Effect of Underdrainage on Subsequently Placed Lifts

149. The effects of underdrainage systems on subsequent lifts placed over material previously dewatered are not well-known. At the time of report preparation, field experiments were being conducted to evaluate: (a) the effects of sand drains placed through the first (dewatered) lift into the underdrainage layer, and (b) the effect of filling desiccation cracks (produced in the dredged material by a combination of underdrainage and surface drainage improvement) extending from the surface to the underdrainage layer with sand prior to disposal.

Preliminary Design and Installation Procedures for Underdrainage Dewatering

Existing pervious foundation

150. If the disposal site has an existing pervious foundation at least 12 in. thick, collector pipes can be placed in the pervious foundation, allowing the foundation strata to act as an underdrainage blanket. Without collector pipes, excess pore pressures will prevent proper drainage.[7] The design of a proper underdrainage system is highly site-specific, but calculations may be made without difficulty for the particular site of interest.[16,17] For dewatering in a pervious 12-in. foundation layer, 4-in. slotted or perforated collector pipe installed on 50-ft centers with minimum 2-in. cover is usually adequate.[15] If a greater collector pipe spacing is used to reduce cost, the underdrainage system will still function, but at a slower rate. The collector pipe system should be designed and placed with flow gradients leading toward central collector points, which may be located in conjunction with

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perimeter outflow weirs. If vacuum pumping is to be used, either as part of the original design or as an alternative, the collector system should be designed to facilitate location of pumps, power sources, etc., adjacent to the main collection points.

151. Trenches for collector pipe may be made by hand or by conventional small endless-bucket-chain trenching equipment. An alternative worth considering is use of a low-ground-pressure tracked vehicle and drag plow described in Part II (Figures 24 and 25) to make a proper trench. The vehicle can operate on relatively soft saturated sand, and the vee-shaped ditch produced by the plow minimizes trench side sloughing and caving. Alternatively, a square trench (Figure 24b) may be produced. The collector pipe may be laid in the trench, blocked to proper grade, and then backfilled using material placed on either side of the trench by the plow. A low-ground-pressure vehicle equipped with dozer blade can be used in the covering operation.

Placement of underdrainage
material on impervious foundation

152. When placing underdrainage material over an impervious foundation, two choices are available: (a) creation of a drainage blanket and collector pipe system covering the entire site, or (b) creation of a radial or herringbone-type underdrainage layer containing collector pipe. Which of the choices is most appropriate and cost-effective is again a site-specific design problem. Data for such computations and decisions are available elsewhere.[16,17] One method of placing underdrainage material from off site is by end-dumping and dozer-spreading in a minimum 12-in. lift, with trenches opened in the spread underdrainage material and collector pipes installed after placement. Hydraulic placement of the free-draining material by use of a small dredge or sand pump should also be considered, and may be more cost-effective if the pumping distance is short and such equipment is readily available at reasonable cost. In this instance, the collector pipe can be placed and blocked to grade before the underdrainage material is placed.

Placement of underdrainage material over previously dewatered fine-grained dredged material

153. At disposal site locations where surface drainage improvement by progressive trenching has been carried out and existing surface crust has formed, this crust should contain a network of interconnected graded surface trenches leading directly to outflow weirs. An expedient method of using underdrainage to accelerate dewatering of a subsequently placed lift would be to fill the trenches with free-draining underdrainage material and install collector pipes. Such an underdrainage system could be installed with a minimum of time and cost and, while it may not function as effectively as a drainage blanket placed over the entire disposal area, should markedly increase the rate of dewatering. Information given in Part II should allow prior prediction of what equipment can operate on the dredged material surface during underdrainage layer and collector pipe placement.

Summary

154. The underdrainage concepts described in this Part have not received as comprehensive and varied a field evaluation as the surface trenching concepts described in Part II. However, the theoretical basis for underdrainage had long been well-understood, and both laboratory and field experiments have verified theoretically predicted behavior. At this stage of development, the major unknown is not if the concepts will work for fine-grained dredged material, but exactly what dewatering rates may be expected for the various concepts, when applied to various types of fine-grained dredged material on a site-specific basis. Research currently under way should help to provide additional reliable field data. In the interim, laboratory testing of channel sediment[1B,15] should allow a more nearly accurate site-specific prediction of expected underdrainage effects and, if used in conjunction with a predictive method which properly considers time effects,[5] represents the best state of the art for final design.

PART IV: CONTAINMENT AREA OPERATION AND MANAGEMENT TO FACILITATE DEWATERING

Introduction

155. To facilitate application of previously described dewatering techniques and maximize available disposal volume and thus useful disposal site life, numerous operation and management concepts may be applicable to an overall site management plan. Most of these concepts involving long-term disposal site management will result in increased capital construction and manpower/administrative costs. However, in most instances, the unit disposal cost of operating the site over the design life will be equal to or lower than costs for an unplanned operation. Thus, when incorporating the subsequently described procedures in an overall plan, the total cost, both short- and long-term, of concept implementation should be considered.

156. Application of any general concept to a given disposal site is a site-specific design problem. Whether or not any concept will prove feasible can only be determined after careful planning and study, not only of the concept itself, but of the alternatives to and constraints involved in concept implementation. The concepts described herein are presented in general terms, and some of the expected results and side effects inherent in their implementation are discussed. Operation and management concepts have been grouped into three general areas: those concepts that may be implemented prior to disposal, those concepts that may be implemented during the disposal operation, and those concepts that may be implemented after the disposal operation has been terminated and prior to a subsequent disposal operation. More detail on some of the concepts is available elsewhere.[18]

Concepts Applicable Prior to Disposal

Thin lift placement

157. Advantages of thin lift placement. The thinner the lift of

fine-grained dredged material placed in a disposal area, the more rapidly the entire lift may be dewatered and returned to more stable soil form. In its simplest form, application of the thin lift concept would require enough disposal area acreage such that resulting periodic disposal operations would place relatively thin lifts of material over the entire area. An "optimum thin lift," as discussed herein, is arbitrarily defined as one which would occupy a vertical thickness of 3 ft or less when the material reaches the decant point of about 1.8 times its LL. This thickness of material may usually be dewatered in a 12-month period by application of either underdrainage or improved surface drainage methodology.

158. The primary advantage of placing material in optimum thin lifts is that, in most instances, the progressive trenching dewatering process may be carried out entirely with the RUC. Thin lift concepts may also be useful when necessary disposal operations result in placement of small amounts of dredged material (in very thin lifts) at frequent intervals, rather than the normal procedure of placing large quantities at longer intervals. In such instance, the RUC could conduct semicontinuous surface trenching operations and cause dewatering of each thinly placed lift prior to subsequent lift placement.

159. When existing conditions do not allow placement of optimum thin lifts, it is still possible to obtain complete lift dewatering if the total lift thickness does not exceed the "maximum thin lift thickness," i.e., the placed thickness of material, measured when the material reaches the decant point, that may be completely dewatered by use of Part II and/or III methodology before the beginning of the next disposal cycle. The "maximum thin lift thickness" is thus a function of channel sediment engineering properties, existing climatic conditions, and the expected dredging/disposal interval. Previously described and referenced predictive methods may be used to estimate this maximum thickness.

160. <u>Possible formation of internal drainage network.</u> If a thin lift is dewatered completely, such that desiccation cracks exist throughout the dewatered lift, a subsequently placed lift will

initially fill desiccation cracks with freshly placed slurry. However, once disposal is terminated, self-weight consolidation will occur in the new material overlying the previous lift, while, at the same time, a moisture imbalance will exist between the relatively drier crust desiccation blocks and the wet slurry filling the desiccation cracks. As moisture equilibrium occurs, water is absorbed by the crust blocks and shrinkage occurs in the wet material filling the desiccation cracks. This shrinkage will allow some downward movement of the overlying dredged material, but bridging and arching may occur such that smaller desiccation cracks will exist underneath the recently placed lift.

161. Once this phenomenon has occurred, an interconnected set of desiccation cracks may act as an underdrainage system for the recently placed lift, with downward migration of water from the recently placed dredged material into the desiccation crack network and drainage through the desiccation crack network to perimeter ditches maintained around the disposal site. This behavior was noted to occur in disposal areas of the Charleston District, where perimeter dragline trenches were maintained starting immediately after dredged material deposition. Water drained continuously from the dredged material, and a much higher rate of interior site dewatering was noted than could be expected from only perimeter dragline trenching operations.

162. Constraints on thin lift placement. The primary requirement for implementing thin lift disposal concepts, that of sufficient disposal area acreage, may be the most difficult item to obtain, particularly if the project sponsors must provide disposal acreage, often working in conjunction with private landowners. The project sponsor may not initially appreciate the need for providing long-term commitments for more acreage than is necessary to contain disposal contemplated in the immediate future unless it is shown that more nearly stable land is created by continually dewatering thin lifts, thus resulting in a better end product when the disposal site is returned to the project sponsor or private landowner.

163. Possible needs for disposal area partitioning. Large disposal areas are often more difficult to operate and maintain than

smaller areas. In particular, difficulty may be encountered in placing material properly in a large disposal area to obtain proper thin lift thickness and surface topography sloping from dredge pipe locations to outflow weirs. Without this surface topography gradient, it will be difficult to initiate future improved surface drainage operations. These problems may, in many instances, be overcome by subdividing a large disposal area into smaller areas with cross dikes or other internal partitioning, if the resulting smaller areas are still hydraulically efficient. The best way to determine whether or not thin lift placement concepts are applicable at a specific site is to compare the total cost of construction and operation by both thin and thick lift placement concepts and then evaluate the benefits resulting from both methodologies.

Site leveling,
clearing, and grubbing

164. Disposal site construction may result in building a perimeter dike around the disposal site location, without considering the existing topography and vegetation contained inside the dike. Since alteration of internal surface topography and clearing and grubbing of existing vegetation would result in increased disposal area construction costs, this operation should not be undertaken unless it will produce worthwhile benefits. However, presence of large vegetation may inhibit flow through the containment area, resulting in undesired placement and surface topography of the disposed material. This undesirable topography may inhibit future surface trenching operations during an active dewatering phase. Irregularities in disposal area foundation topography will also be directly reflected in the surface of the filled disposal site. Thus, failure to obtain proper grading from dredge pipe location to outflow weirs prior to disposal may result in irregular surface topography, which will inhibit initial attempts to conduct surface trenching operations and may trap numerous pools of ponded surface water, inhibiting dredged material surface drying. If the overall management scheme for the disposal area calls for future application of progressive trenching concepts, it may be beneficial to properly clear

and grade the disposal area foundation prior to initial disposal. Additional costs incurred may be returned in benefits from facilitating future conduct of a surface trenching program.

165. If the disposal area foundation contains suitable borrow, high-bid contracts may be let for removal of this borrow prior to initiation of disposal operations. Removal of foundation material prior to disposal will increase total disposal volume, and thus the useful life of the disposal site. During borrow removal operations, appropriate site grading, clearing, and grubbing may be carried out. Funds obtained by sale of the borrow may be used to reduce the total cost of disposal site construction.

166. If the disposal site has a pervious foundation, and if the dredged material is to be dewatered after placement, use of underdrainage should be seriously considered. If underdrainage is contemplated, it should be fairly easy to install once the disposal site surface foundation has been graded properly and/or suitable borrow has been removed prior to disposal. Procedures for installing underdrainage were discussed in Part III.

Placement of permanent inlet
piping system and outflow weirs

167. General use in site operation and management control. In conventional disposal area construction, it is normal practice to place outflow weirs on the site perimeter adjacent to the water and locate the dredge pipe inlet as far away as practicable from these outflow weirs. However, if the disposal area is large, or if it has irregular foundation topography, considerable difficulty may be encountered in properly distributing the material throughout the area and obtaining surface elevation gradients necessary for implementation of a surface trenching program. One alternative is to use interior or cross dikes to subdivide the area and thus change the large area into several smaller areas. Effective operation by this procedure requires that the dredge pipe location be moved periodically from one part of the site to another, to insure a proper filling sequence and obtain proper surface elevation gradients. Also, shifting input flow from one point

a. Creation of interior cross dike by controlled deposition of coarse-grained material along proposed dike alignment

b. Deposition of coarse-grained material adjacent to perimeter dike to facilitate future dike raising

Figure 37. Temporary "header and gun" disposal system used by the Aluminum Company of America to place the coarse-grained fraction of bauxite processing mud at desired locations

deposited directly along the proposed cross dike alignment. Coarse-grained material falls out of suspension quickly along the alignment, and fines are carried away on both sides. The net result of the depositional process is construction of a desired cross dike, subdividing the disposal area into smaller and more easily manageable segments, as a part of the disposal process. The cost of purchasing and placing the header system and the cost of the additional manpower required for proper header system operation during disposal are considerably less than costs for conventional cross dike construction.

170. The other alternative, that of depositing material from the header system along the interior of the disposal site perimeter dike, allows the coarse-grained fraction to fall out of suspension quickly while the fines are carried farther into the disposal area. By this process, the coarse-grained material most suitable for use in future dike raising activities is placed along the inside perimeter of the dike, where it may be handled by dragline and used to raise the dike height. The material does not have to be borrowed and transported to the dike alignment, and costs of obtaining, installing, and operating the perimeter header system are normally less than the costs of borrow and transport of the material from some central location where it would be deposited by a single dredge inlet pipe. The procedure used for dike raising in these instances is to continually berm inward as dikes are raised. By use of the perimeter header and gun disposal process, the foundation for the inward berm is essentially coarse-grained and stable material rather than fine-grained and less stable material.

171. Installation and operation of numerous outflow weirs. In conjunction with provisions for moving the outflow point over the disposal site, it may also be worthwhile to contemplate installation of more outflow weirs than would be required by current design methods. Availability of more outflow points allows greater flexibility in site operation, and greater freedom in movement of dredge outflow points while still maintaining flow distances required to obtain satisfactory suspended solids concentrations in disposal site effluent.[6] Also, a higher degree of flexibility in both disposal site inflow and outflow

control will allow operation of the area in such a manner that desired surface topography can be produced, facilitating future surface trenching operations.

172. Placement of dredge pipe outlet in center of disposal area. When a disposal site with soft foundation is filled, foundation consolidation produces a saucer-shaped configuration, resulting in a tendency for ponding in the center of the saucer (disposal area) and necessitating considerable surface trenching effort to drain trapped surface water and facilitate evaporative drying. Such problems may be minimized by locating the disposal pipe in the approximate center of the disposal area or disposal area compartment, resulting in placement of a mound of material at the point where maximum settlements are likely to occur, and causing initial surface topography sloping from the center of the disposal site to outflow weirs located around the perimeter. Resulting maximum consolidation settlements in the center of the disposal area will be compensated, to a great extent, by the higher initial thickness of material, such that site drainage toward perimeter outflow weirs is facilitated. This procedure has been used in England to facilitate evaporative dewatering and proper drainage of confined dredged material.* While the distance between inflow and outflow points is effectively halved, nevertheless, if the inflow point is properly constructed with baffle, vertical discharge, or similar arrangement, the outflow velocity will be at least halved also, such that the resulting detention time in the disposal area will be the same as for conventional disposal practice.

Interior dike construction

173. Need for interior dike construction. The basic rationale behind construction of interior disposal area dikes is to subdivide the area into more manageable segments and/or to control the flow of dredged material through the disposal area. Control of material placement is normally to facilitate future disposal site operations, such

* Personal communication, M. J. Stone, U. K. Manager, Zanen Verspoet, N. V., 17 Pyle Hill, Newbury, Berks, The United Kingdom, November 1977.

as dewatering, or to provide proper control of disposal area effluent. Considerations relative to interior and cross dike construction and site operation to minimize suspended solids concentrations in disposal site effluent are beyond the scope of this report; procedures for such design are available elsewhere.[6,19]

174. As a general rule, use of interior cross dikes in any disposal area will increase the initial cost of construction and may result in increased operating costs. However, facilitation of disposal site operations, particularly future dewatering, may result in a general reduction in unit disposal cost over the life of the site. A comment often made relative to interior cross dike construction is that this construction will reduce the available disposal volume. The benefit derived from dikes should be evaluated against the amount of disposal volume required for their construction. Further, if the dikes can be constructed from material available in the disposal site foundation and subsequently raised with dewatered material, the net decrease in storage capacity will be approximately zero.

175. Disposal site operation in series subareas. Cross dikes may be used to control and direct the inflow and are normally built to allow site subcontainment area (subarea) operation either in series or in parallel. In series, the flow is routed first into one subarea, with sedimentation producing segregation of larger particles, and the overflow from the first subarea routed to a second subarea where finer particles fall from suspension and then perhaps into another subarea, etc., with the outflow point being located at the end of the last subarea. In some instances, cross dikes are built across the entire site width and a long overflow weir is provided to allow outflow into the next subarea in the series, while in other instances spur dikes are built into the containment area, to cause a twisting path for the flow. Criteria for such designs are available.[19]

176. In general, use of series-oriented subdisposal areas should be considered carefully, since the actual result of such use may be the opposite of that desired by the designer.[6] During disposal, coarse-grained sand and gravel will sediment very quickly around the disposal

pipe location. Other material will remain in suspension, depending upon its effective particle size, suspension water salinity, and flow velocity. As a practical matter, a subarea or containment basin to trap or separate specific silt and clay sizes is rather impractical. A rational design for a series of subareas might require an initial subarea to trap sand and gravel, with the remainder of the material, i.e., the fine-grained fraction, going to a larger subarea. Then, if desired, a final subarea could be used to catch colloidal solids and other suspended fine material and provide a proper detention time, perhaps in conjunction with use of chemical flocculants, to maintain proper water quality in the disposal area effluent. However, there is essentially no need to construct an initial subarea to capture the coarse-grained fraction, as it will usually sediment (on its own) into a coherent mass. Also, when designing the series of subdisposal areas, care must be taken to obtain adequate size. If the first subarea in the series is filled, it will no longer function and provide required detention time, and its function must be assumed by the next unit in the series. Also, it should be noted that, unless wide inflow and outflow weirs are used in each of the subareas, low-energy areas or "dead corners" will be created in each subarea and the effective size of the disposal area (in terms of extent needed to reduce flow velocities to desired levels) will be reduced. This condition may also be encountered when a series of spur dikes is extended into the disposal area to direct the flow. The net result of each spur dike construction may be to create a large number of low-energy/dead corner areas and channelize the flow in a serpentine path between the spur dikes at a much higher velocity than would be expected were the spur dikes not present.[19] During any type of series containment subarea operation, low-energy areas and dead corners will cause irregular site topography to be created, thus producing numerous localized depressions which will retain precipitation and interfere with future surface trenching dewatering operations.

177. Disposal site operation in parallel subareas. To facilitate site dewatering, operation of interior compartments on a parallel basis

appears more promising. In this concept, flow is initially routed into one compartment, then, when it is filled to the proper depth or when suspended solids concentration standards in the effluent are exceeded, the flow is routed to another portion of the site. This procedure allows more carefully controlled placement of material to the desired thickness throughout the site. Also, in some measure, it may help to compensate for the differences in total inflow rate possible from the variation in dredging equipment that may result from open contract advertisement (i.e., it is easier to compensate for the effects of a large versus small dredge when parallel compartments are used). A hypothetical design involving parallel compartments is shown in Figure 38, where the dredge pipe is placed across the center of the disposal area and inflow is routed into long compartments with outflow weirs at each end. While the effective distance between inflow and outflow points is half that if the conventionally used design procedures were adopted, the net flow velocity is also halved. As a result of the operation, twice as many weirs are available for release of effluent, and, using the indicated depositional process, a surface elevation gradient is created from the center of the disposal area toward each outflow weir, facilitating future surface drainage. Flow may be routed to each of the compartments during the disposal operation in such manner as necessary to produce desired surface elevation gradients and lift thicknesses.

178. If the disposal site is large enough to contain material from several periodic dredgings, each compartment may be used sequentially for a separate operation. In this manner, a sequence such as the following may be developed. The first compartment is filled and, after decant, dewatering operations are initiated. As dewatering operations proceed the next disposal is placed in the second compartment and subsequent disposal in the third, etc. While fresh material is being deposited in part of the site, the dewatered material from the initial placement may be borrowed and used to raise perimeter dikes, facilitating reuse of the initial subarea. This sequence of operations is shown in Figure 39.

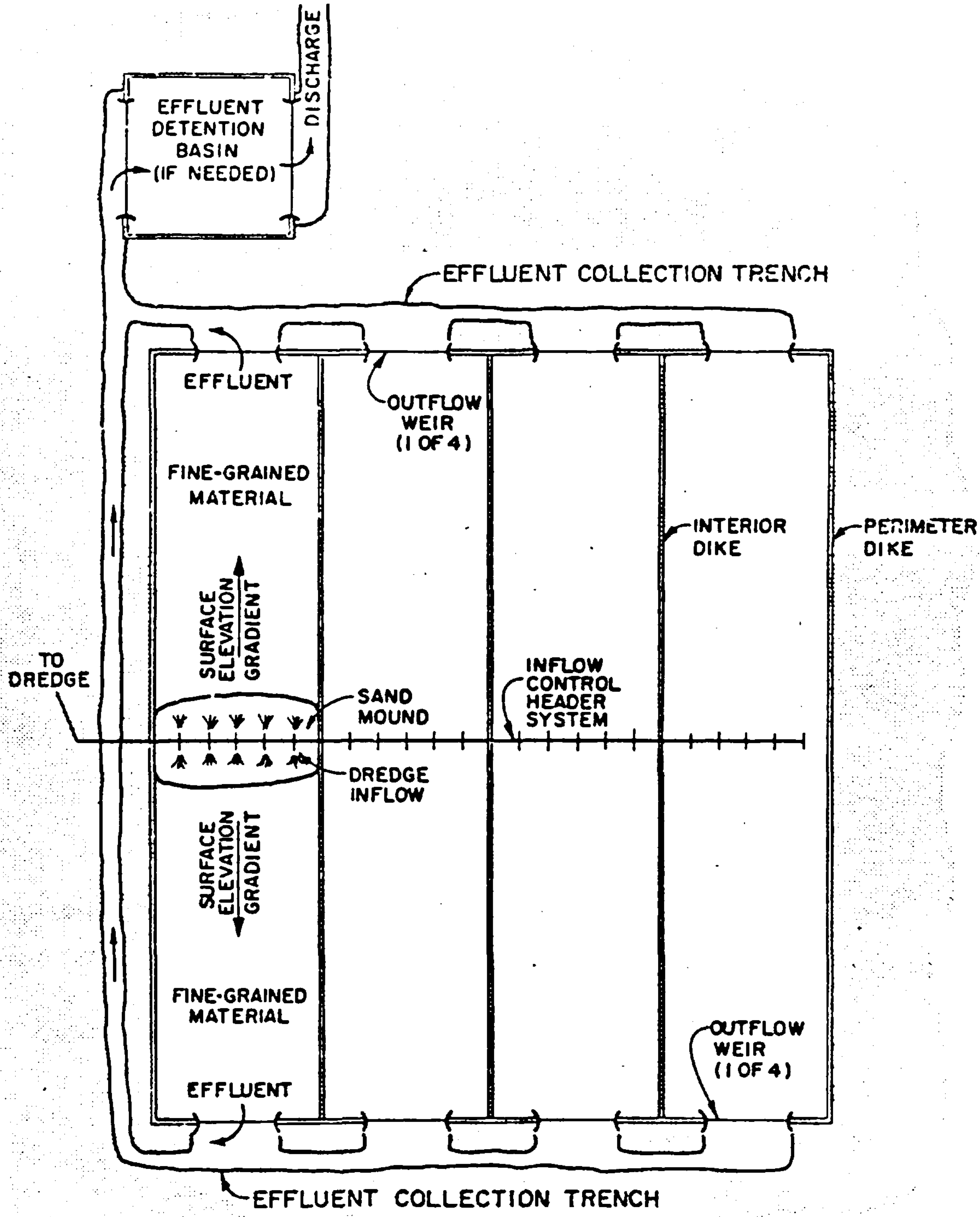


Figure 38. Conceptual illustration of disposal site layout to permit parallel compartment use and produce surface topography facilitating future dredged material dewatering

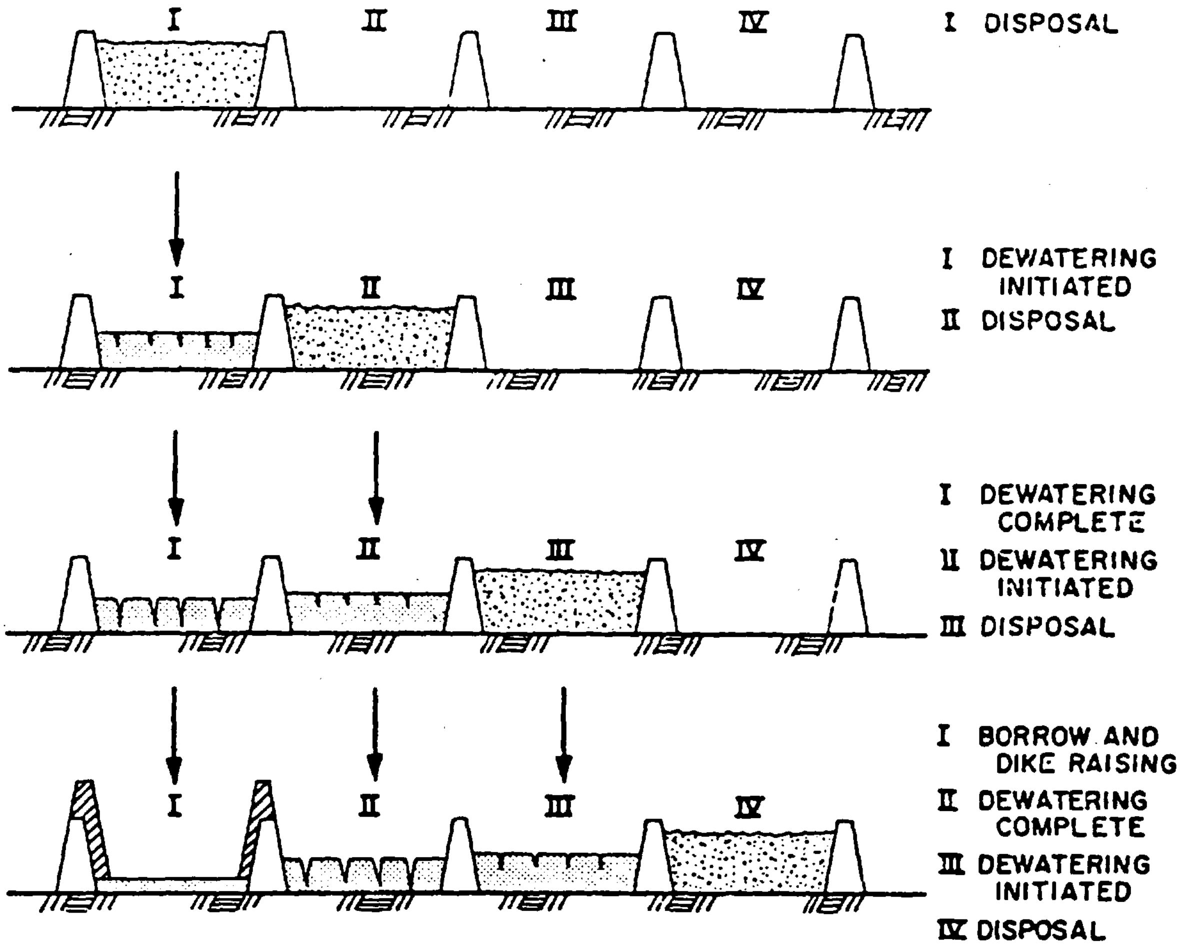


Figure 39. Conceptual illustration of sequential dewatering operations

<u>Improvement of site access</u>

179. When the long-term operation and management plan for a disposal site includes provision for future dewatering activities and/or removal of dewatered material for dike raising or other productive use, the plan will be facilitated if, at the time of disposal site construction:

- a. Adequate provision is made for improved site access.
- b. Proper initial dike design is carried out so that an adequate base section will exist for future raising activities.
- c. If necessary, internal cross dikes and other appurtenant structures are installed while it is most easy to do so.

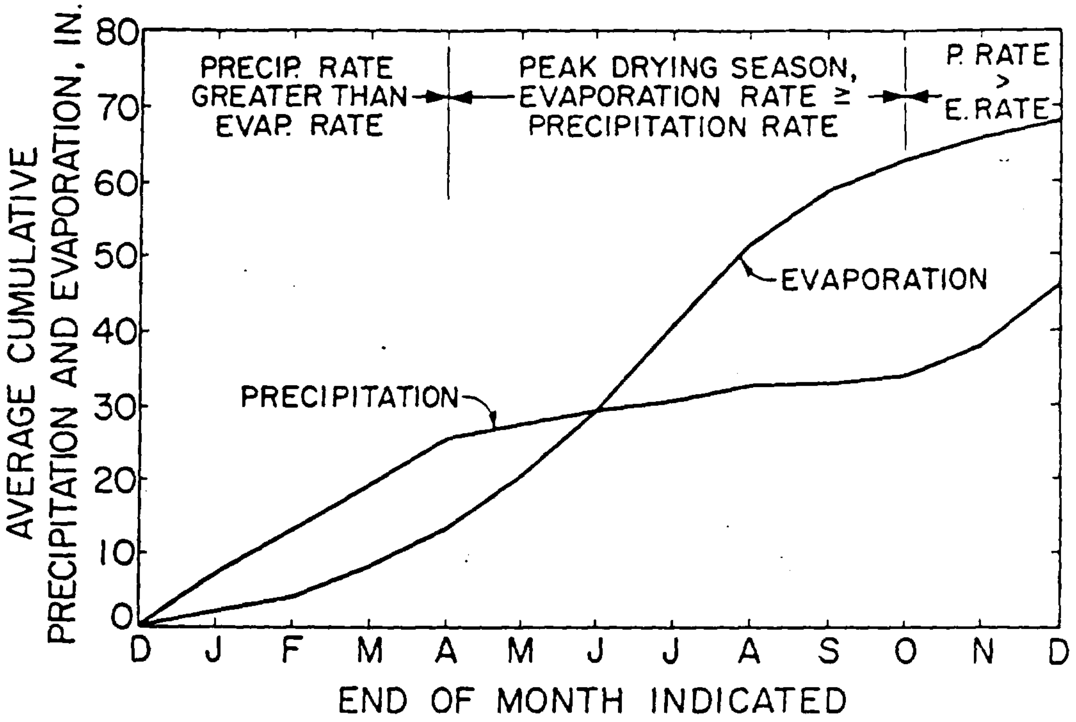
If future borrow of interior dewatered dredged material is contemplated, it may be most cost-effective to construct small access roads into the area, as a substructure for future haul roads or dragline access. Such stable platforms may be covered with some fine-grained dredged material, but their emplacement in the disposal area will allow subsequent equipment operation without immobilization.

Scheduling of dredging operations to take maximum advantage of climatic conditions

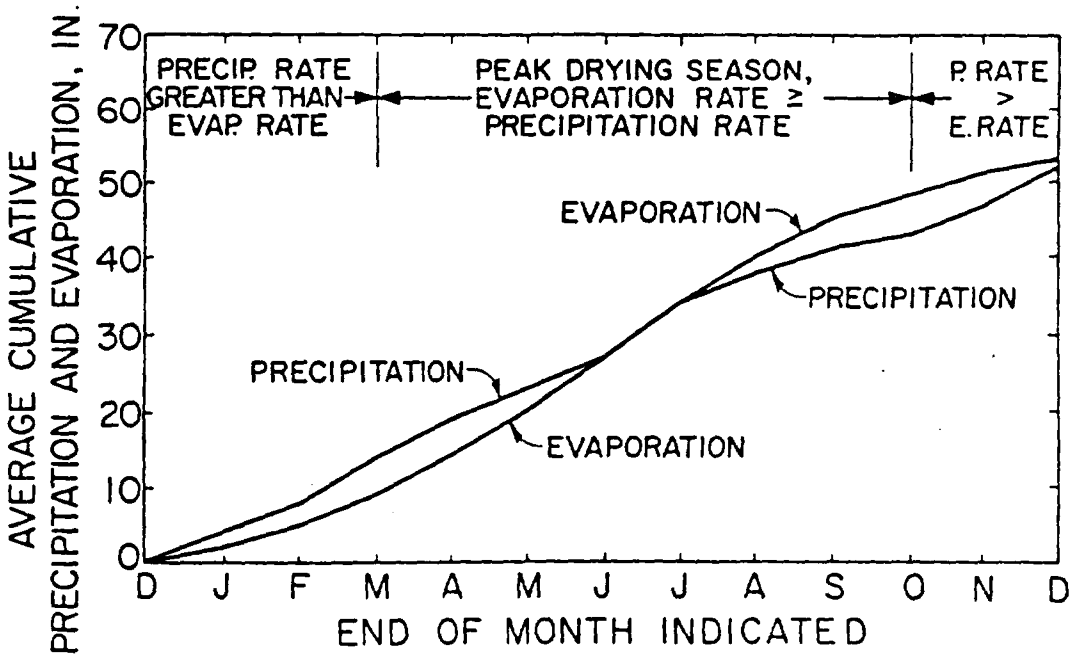
180. Many non-engineering considerations affect the actual time during which disposal operations are conducted. They include:

- a. Expenditure of funds with respect to the fiscal year.
- b. Relative priority of the operation with respect to other work.
- c. Lag time necessary to obtain proper specification preparation and contract advertisement.
- d. Variation in time when the contractor must move on the job.
- e. Size of dredge.
- f. Existing weather conditions.

Nevertheless, considerable advantage may be gained, in an engineering sense, from scheduling disposal operations to occur at appropriate periods of the calendar year, depending upon prevailing climatic conditions. By conducting the disposal phase during a period of relatively low evaporative demand, the initial post-disposal activity (i.e., decanting and gradual reduction of ponded water depth) will occur when minimum evaporative forces are available for dewatering. If the disposal operation can be scheduled such that the material reaches the approximate decant point water content when seasonal evaporation rates begin to be maximized, evaporative dewatering will be facilitated. Estimation of the calendar period for optimum evaporation, based on projected climatic conditions, is illustrated in Figure 40. Examples are from the San Francisco, Calif., and Mobile, Ala., areas. If possible, disposal operations should be terminated, ponded water removed, and the material sedimented/consolidated to the decant point by the time (calendar month)



a. San Francisco, Calif., area



b. Mobile, Ala., area

Figure 40. Illustrations of method for estimating calendar periods when evaporation rates are maximized

when the evaporation rate begins to increase. Methodology is available[5] for prediction of the time lag between termination of disposal and dredged material sedimentation/consolidation to the decant point, for site-specific conditions.

Concepts Applicable During Disposal

181. Since it is normally inappropriate and undesirable to terminate or interrupt the contractor's operations once the disposal process has been initiated, the majority of site operation and management procedures and improvements must be implemented either prior to or after termination of disposal operations. During disposal, a primary operation and management requirement is to operate the site according to previously developed guidelines, without causing downtime to the dredging contractor. If appropriate operational plans and guidelines have not been developed prior to initiation of disposal, it is often too late to develop and implement such concepts once disposal has commenced.

Concepts Applicable After Termination of Disposal

182. As soon as disposal operations are terminated, it is advantageous to remove ponded surface water as rapidly as possible, consistent with meeting suspended solids concentrations criteria for the effluent. Thus, after disposal, an active program of monitoring internal water levels and removing weir boards as rapidly as possible should be maintained, so that when the dredged material reaches the decant point the surface will be exposed to evaporative drying, and thin skin formation, such as shown in Figure 1, will occur rapidly. Obviously, this drying skin will not form if the surface is covered with ponded water.

183. After the material reaches the decant point, surface trenching operations such as those described in Part II may be initiated and any procedures contemplated for borrow and removal of concentrated

coarse-grained material may be undertaken. After the dredged material has been dewatered, following whatever scheme appears appropriate, the material may be removed by conventional or special excavation techniques (see Part II and Reference 20) and used to raise perimeter or interior dikes or for other off-site productive use. Also, prior to subsequent disposal, the trench network created during surface dewatering may be used to form an underdrainage network, as described in Part III.

Summary

184. Various concepts have been described in this Part which, if implemented, should facilitate subsequent site operation and dewatering and reclamation of dredged material. Whether or not any particular concept should be applied will be essentially a site-specific determination, based on available constraints, local sponsor policies, land-use regulations, the actual cost of conducting operations, and whether or not adequate disposal capacity will be available without such additional work. Most of the improvements described herein, while resulting in increased initial construction costs and, perhaps, higher operational costs, may nevertheless result in a lower cost per unit of sediment volume stored during the design life of the site, because their application will facilitate future dredged material dewatering (causing volume creation from shrinkage) and facilitate future dredged material removal and dike raising with dewatered material, also creating more disposal volume.

PART V: CONCLUSIONS

185. The methodology and guidelines presented herein should allow for technically feasible, operationally practical, and cost-effective dewatering and densification of fine-grained dredged material placed in confined disposal areas. The major technical unknown in application of such technology is the exact rate at which fine-grained dredged material dewatering, densification, surface subsidence, and crust formation will occur. Prediction methods and guidelines given and referenced herein represent the current state of the art, and are accurate enough for feasibility determination and, in many instances, final design. Ongoing research should provide additional data for making more precise and reliable prior predictions. In the interim, agencies implementing dewatering technology are urged to maintain detailed records of both actual costs and net effects of technology application. These data will be extremely useful in refining general prediction relationships and in making better predictions for subsequent dewatering efforts.

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APPENDIX A

MONTHLY STANDARD CLASS A PAN EVAPORATION FOR THE CONTINENTAL UNITED STATES

THE FOLLOWING EVAPORATION CHARTS
ARE BASED ON U.S. WEATHER SERVICE DATA

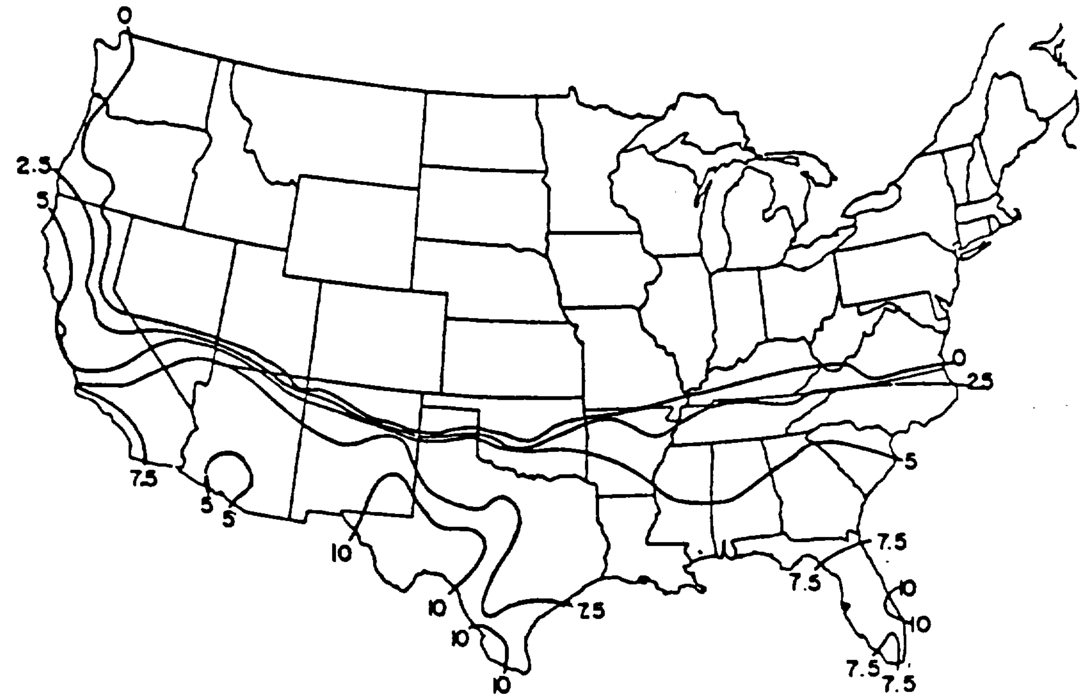

Figure A1. Average pan evaporation, in centimetres, for the continental United States for the month of January based on data taken from 1931 to 1960

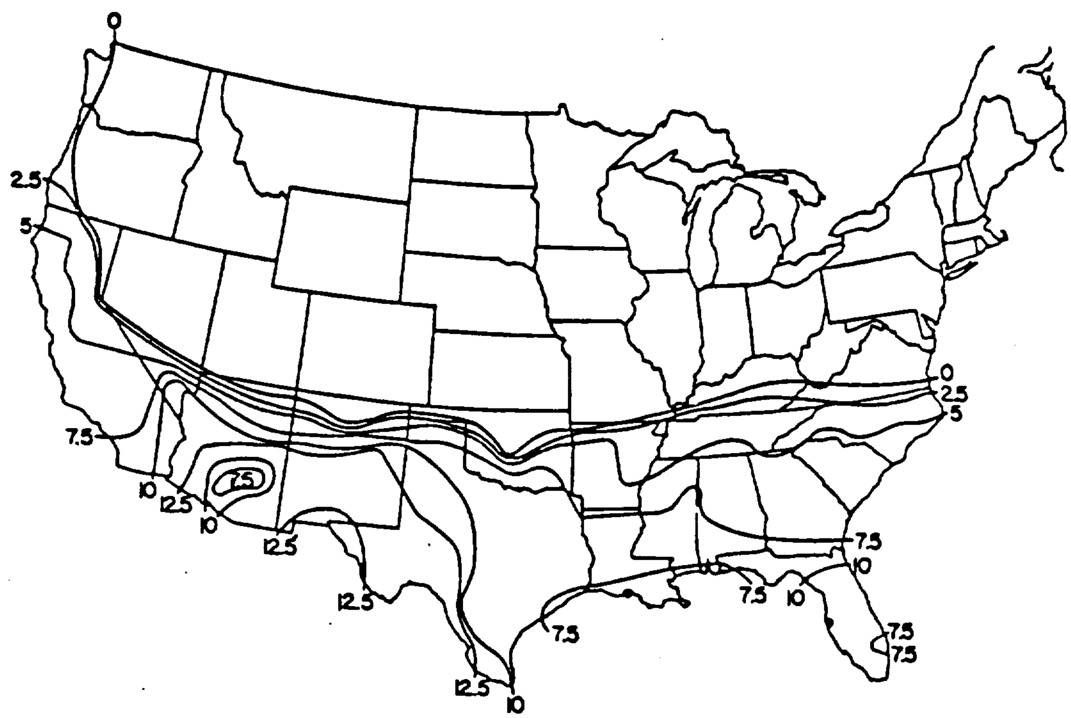

Figure A2. Average pan evaporation, in centimetres, for the continental United States for the month of February based on data taken from 1931 to 1960

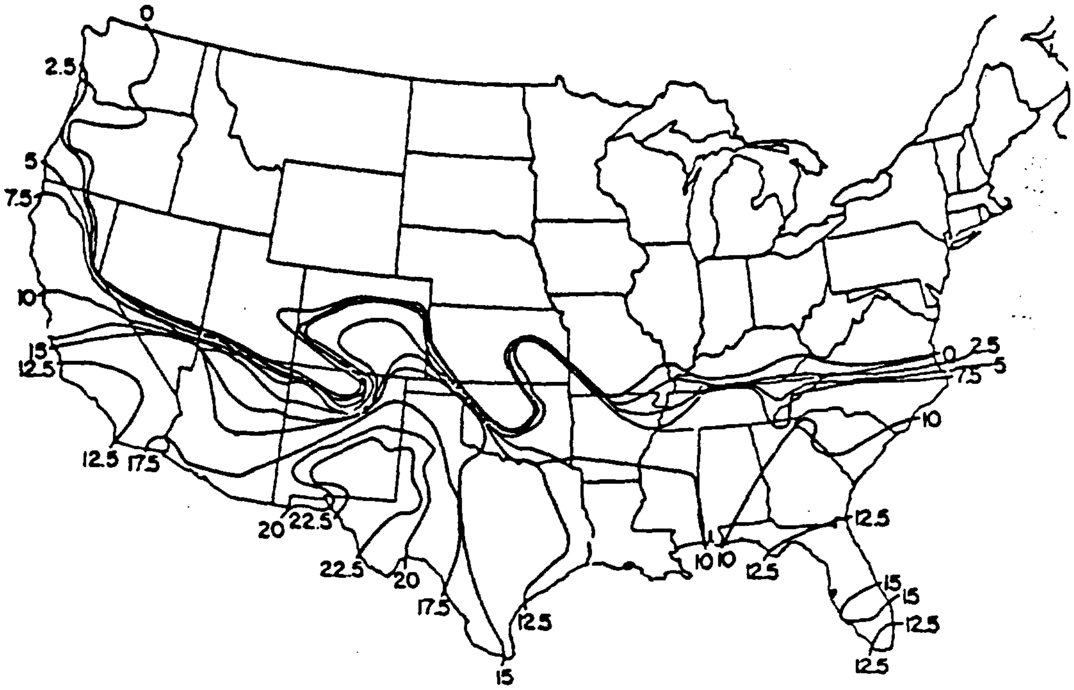

Figure A3. Average pan evaporation, in centimetres, for the continental United States for the month of March based on data taken from 1931 to 1960

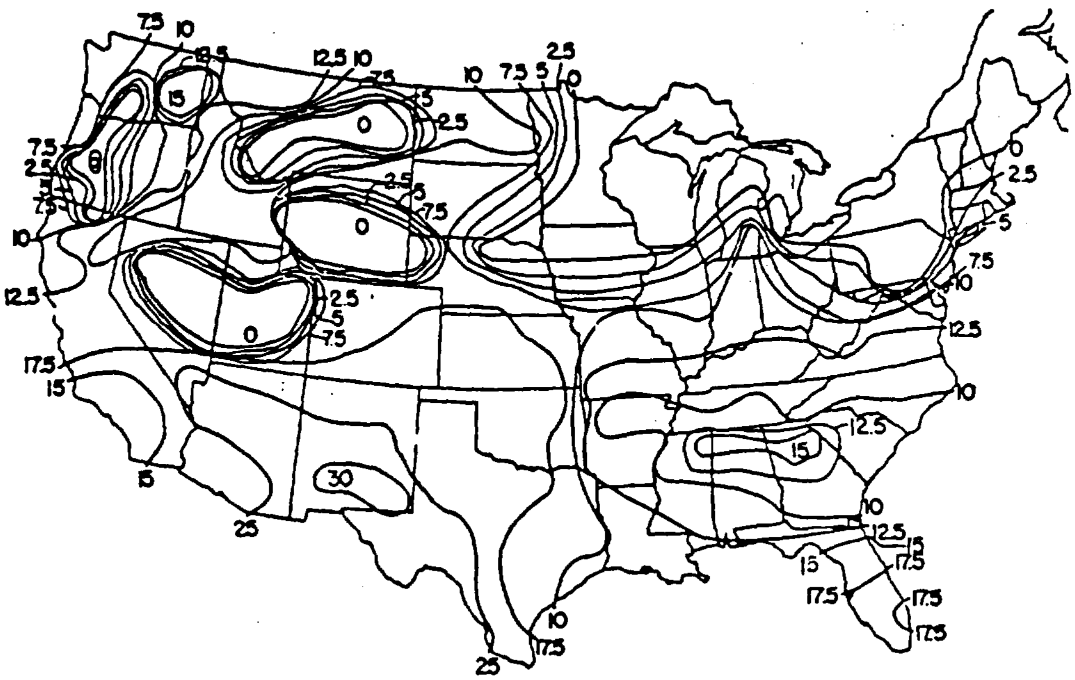

Figure A4. Average pan evaporation, in centimetres, for the continental United States for the month of April based on data taken from 1931 to 1960

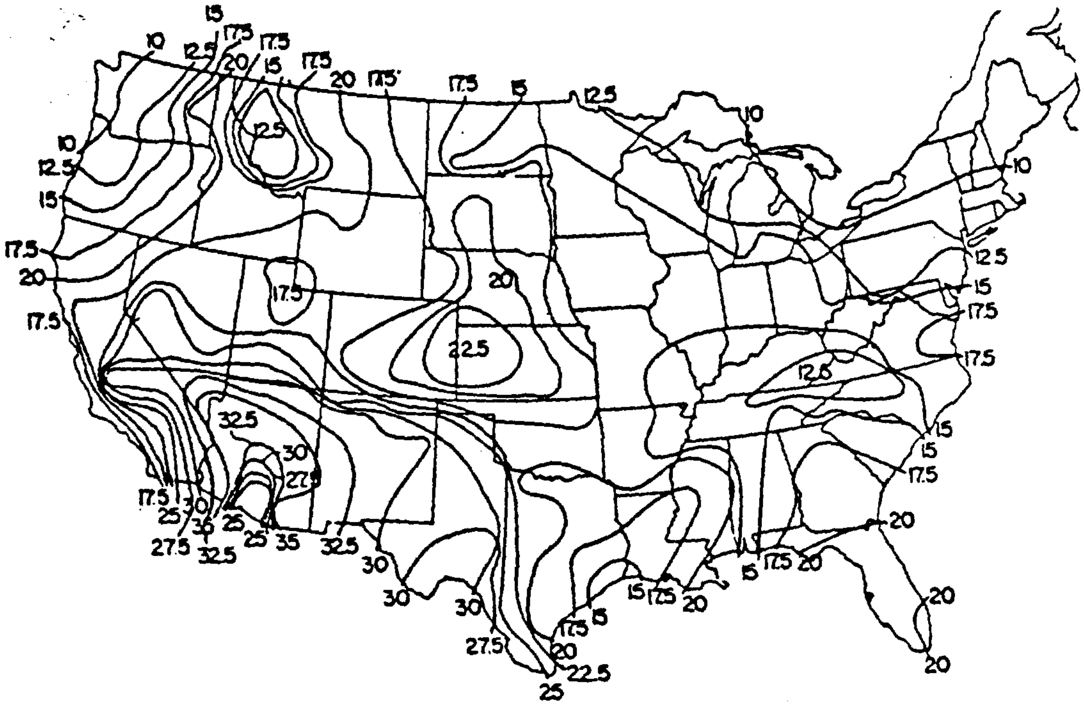

Figure A5. Average pan evaporation, in centimetres, for the continental United States for the month of May based on data taken from 1931 to 1960

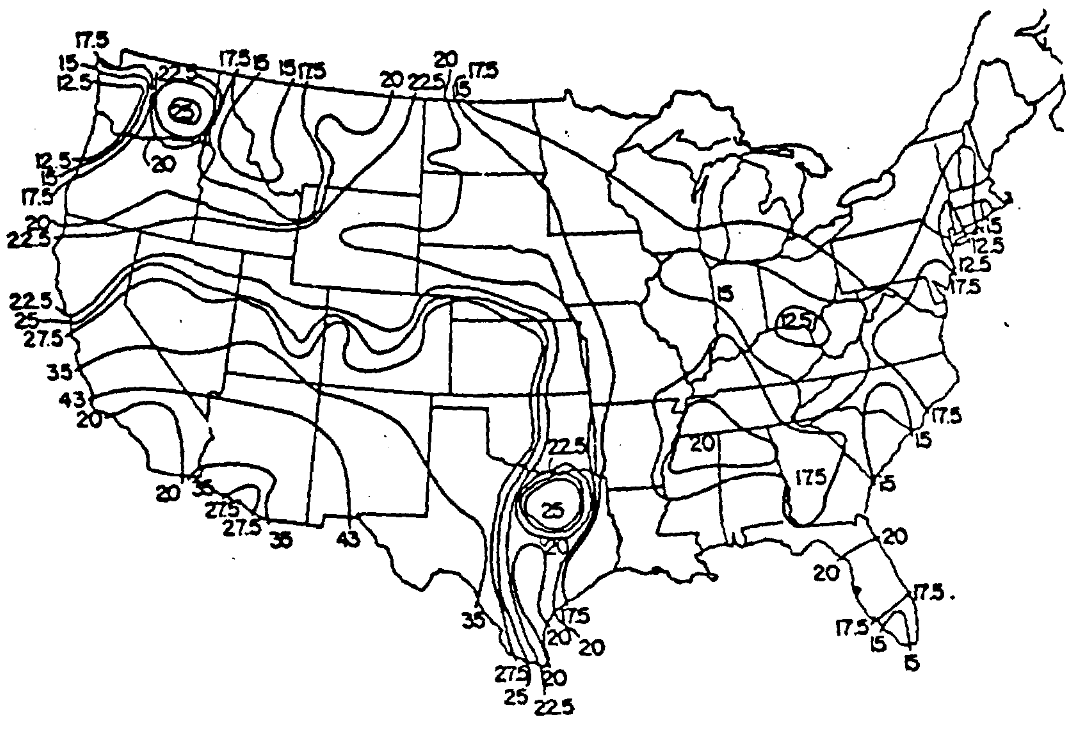

Figure A6. Average pan evaporation, in centimetres, for the continental United States for the month of June based on data taken from 1931 to 1960

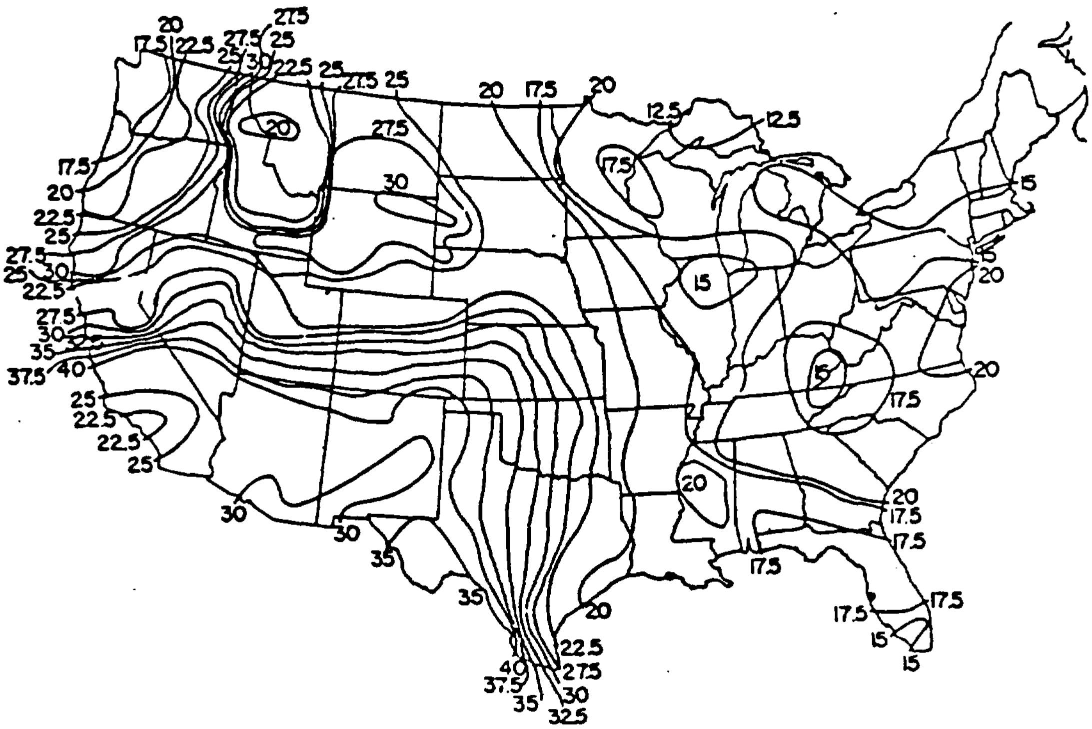

Figure A7. Average pan evaporation, in centimetres, for the continental United States for the month of July based on data taken from 1931 to 1960

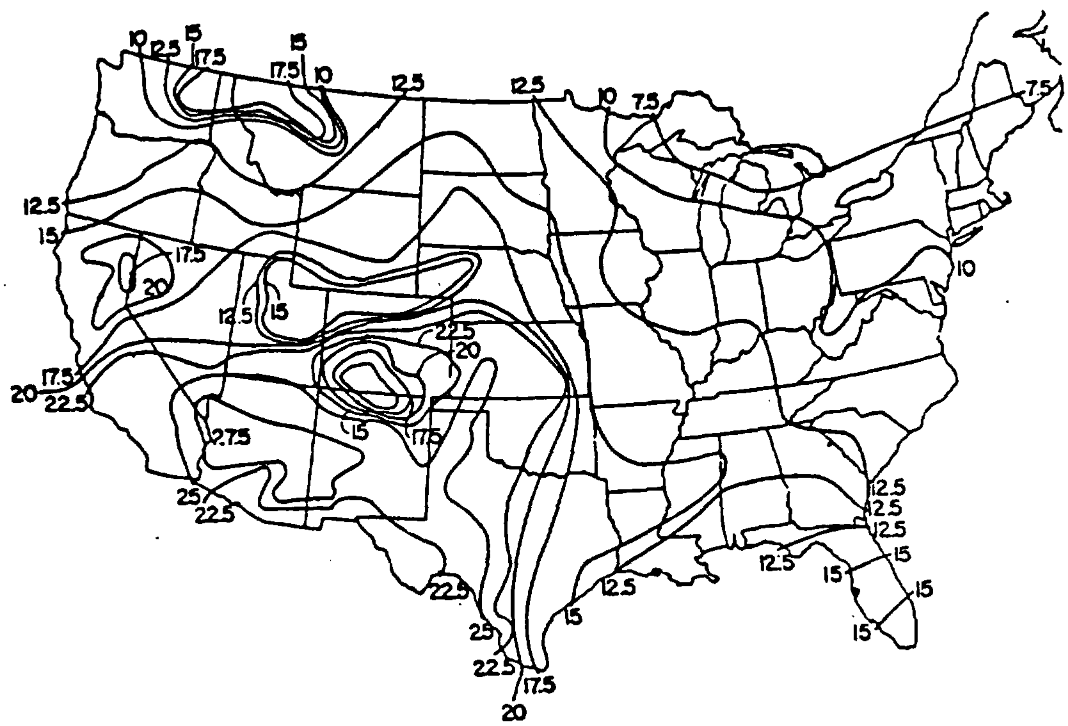

Figure A8. Average pan evaporation, in centimetres, for the continental United States for the month of August based on data taken from 1931 to 1960

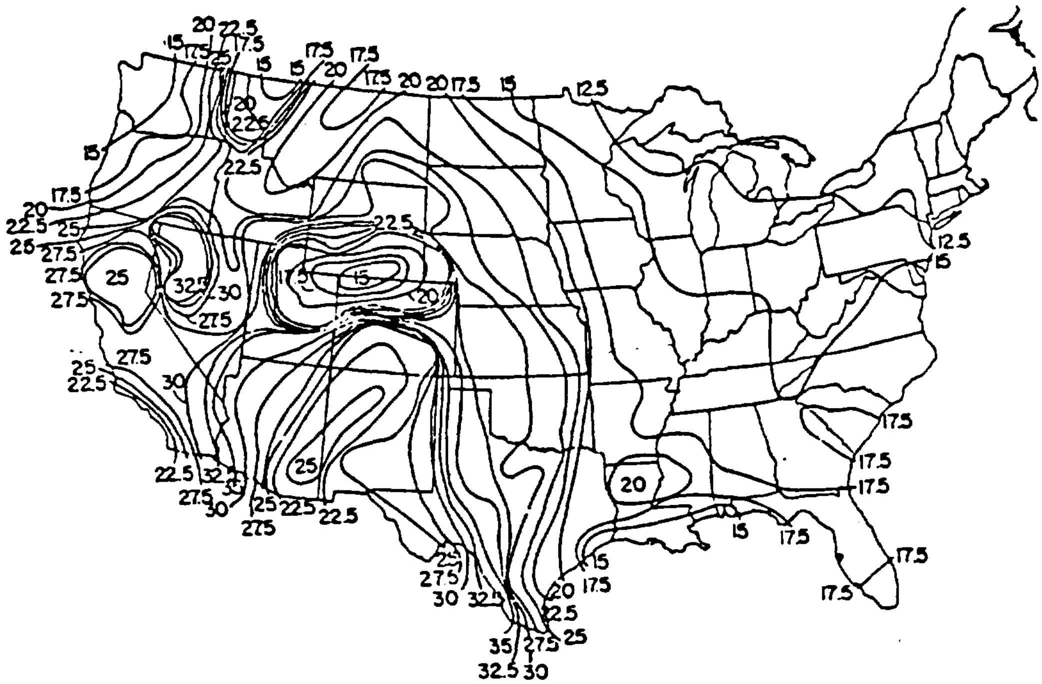

Figure A9. Average pan evaporation, in centimetres, for the continental United States for the month of September based on data taken from 1931 to 1960

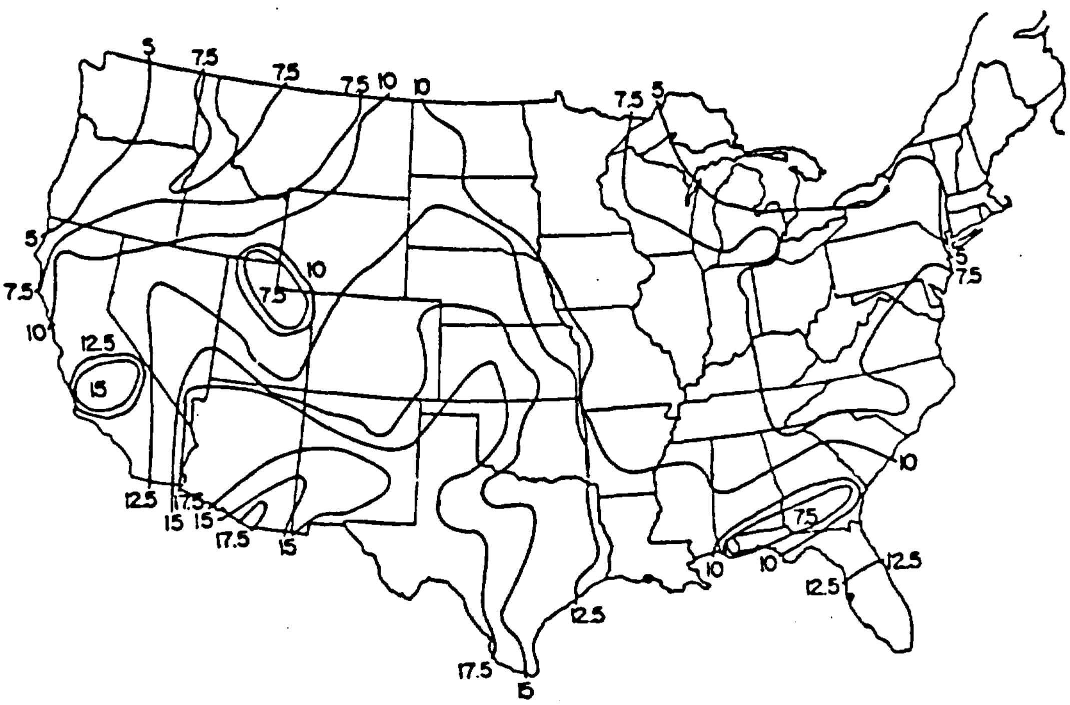

Figure A10. Average pan evaporation, in centimetres, for the continental United States for the month of October based on data taken from 1931 to 1960

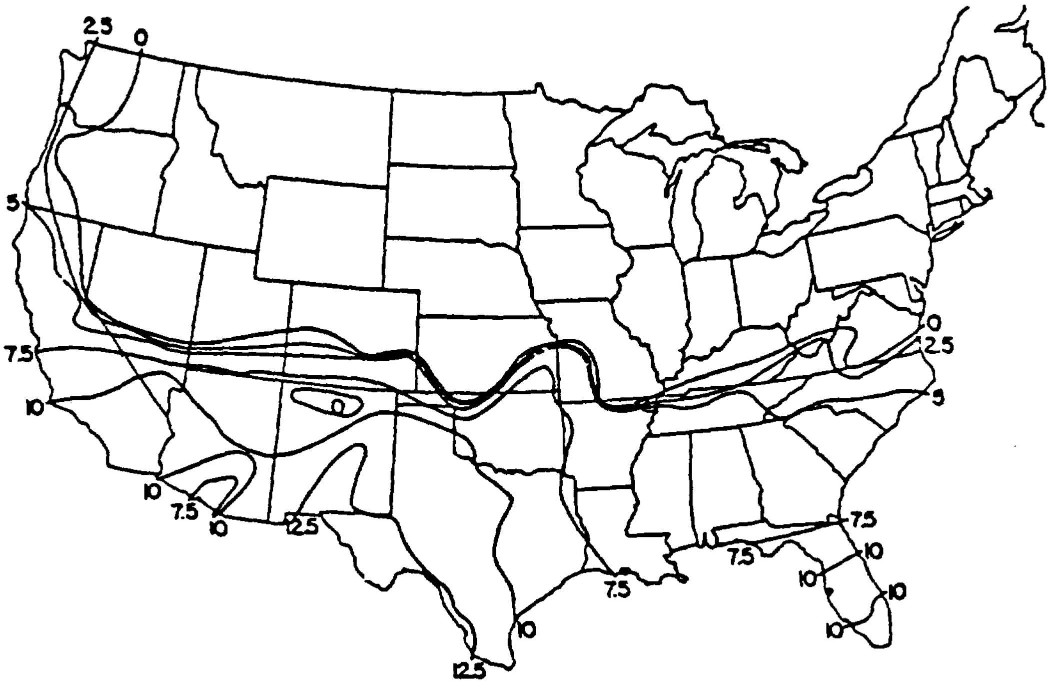

Figure A11. Average pan evaporation, in centimetres, for the continental United States for the month of November based on data taken from 1931 to 1960

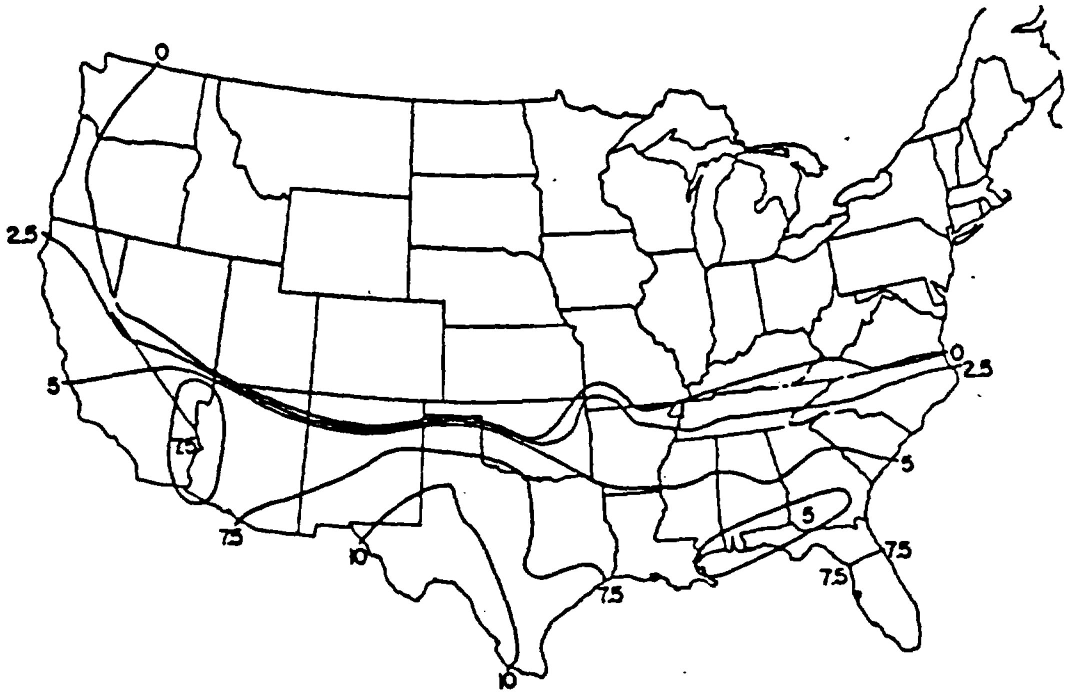

Figure A12. Average pan evaporation, in centimetres, for the continental United States for the month of December based on data taken from 1931 to 1960

*U.S. GOVERNMENT PRINTING OFFICE: 1979 623-744/850 1-3